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**SPACE
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Document No. 75SDS4281

N77-25206

(NASA-CR-150293) STUDY FOR IDENTIFICATION
OF BENEFICIAL USES OF SPACE (BUS). VOLUME
3: APPENDICES Final Report (General
Electric Co.) 26 p HC A03/MF A01 CSCL 22A

Unclass
G3/12 15589

**STUDY FOR
IDENTIFICATION OF
BENEFICIAL
USES OF
SPACE**

(PHASE III)



**FINAL REPORT - VOLUME III
APPENDICES**

CONTRACT NAS8-28179

NOVEMBER 30, 1975
SUBMITTED PER DPD #451,
DR #MA-04

GENERAL  ELECTRIC

STUDY FOR
IDENTIFICATION OF
BENEFICAL USES OF SPACE (B.U.S.)
(PHASE III)

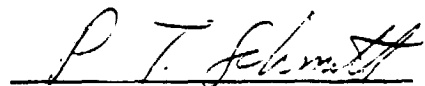
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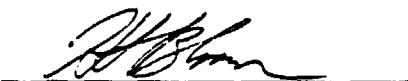
FINAL REPORT - VOLUME III

APPENDICES

November 30, 1975

Submitted Per DPD #451, DR #MA-04


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PREFACE

The Final Report on Phase III of the Study for Identification of Beneficial Uses of Space (B. U. S.) is comprised of three volumes:

Volume I	Executive Summary
Volume II	Technical Report
Volume III	Appendices

Volume II is further subdivided:

- Book 1 - Development and Business Analysis of Space Processed Isoenzymes
- Book 2 - Development and Business Analysis of Space Processed Transparent Oxides
- Book 3 - Development and Business Analysis of Space Processed Tungsten X-ray Targets
- Book 4 - Development and Business Analysis of Space Processed Surface Acoustic Wave Devices
- Book 5 - Study Methods and Trade Studies

General Electric's Space Division, under contract from the NASA's Marshall Space Flight Center completed Phase I of the Study in December 1972, and Phase II in December 1973. In Phase III, the Study has progressed to the Business Analysis and Planning for the commercial development and production of the four products in Phase II:

- Surface Acoustic Wave Components
- Transparent Oxides
- High Purity Tungsten X-ray Targets
- High Specificity Isoenzymes

The methodology employed in the Phase III Study and the results of that effort are reported herein.

In addition to Key Individuals from the participating User organizations who contributed specific product, process, business and planning data in each of their respective areas,

the Study Manager acknowledges the outstanding financial and manufacturing analysis contributions of Mr. P. Schmitt, and the considerable contributions of the following: Mr. U. Alvarado and Mr. M. Clarke of the Study Team in analyzing and organizing the wealth of data accumulated; Mr. K. Taylor, the MSFC Contracting Officers Representative (C.O.R.) for the study, in providing key technical suggestions and direction to the overall effort as well as establishing space processing payload guidelines, Mr. G. Wouch, Dr. E. Okress, and Dr. B. Noval of General Electric's Space Sciences Laboratory, in providing supporting space processing data, and Mr. B. Klawans and Mr. F. Curran of General Electric's Systems Operation and Computations Component in programming and processing "INVEST", the interactive profitability analysis program.

As noted in the Final Reports of earlier Phases, publication of this Phase III report neither implies NASA endorsement of any specific product, process or venture identified during this phase of the Study, nor a NASA commitment to pursue any program defined as part of this Study.

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SECTION I

INTRODUCTION

During the course of the Phase III Study, several key papers were generated. Two contributed directly to approaches adopted in required Study analyses and definitions. One was the result of such analyses and definitions, and it has implications beyond the objectives of this Study.

These three papers are included in this appendix in the interest of providing all key Study data in one report.

APPENDIX A
QUANTIFICATION OF REQUIRED SPECIMEN(S)
FROM SPACE PROCESSING APPLICATIONS EXPERIMENTS
G. WOUCH

INTRODUCTION

Prudent planning of a Space Processing Applications Experiment requires careful treading of the line between miserliness and extravagance. If, in attempting to minimize the cost of an experiment or set of experiments, one fails to acquire a statistically significant number or adequate size of specimens, then one risks drawing conclusions from what may be untypical or incomplete results. Should such unscientific action occur in conjunction with a purely scientific experiment, a subsequent denouement could prove embarrassing to the conclusion - drawer. More important, if such action should influence the direction of an applications development program, then money and time loss could result.

If, on the other hand, one plans an experiment set which provides a large size or number of specimens, one risks requiring funds or requesting other resources (power, cooling, etc.) which could exceed available levels, and thus, could abort the experiment in its conceptual stages.

It is, therefore, incumbent upon the experiment planner to determine, prior to testing or as early in the experiment cycle as possible, the number and size of specimens which will provide the data that is necessary and sufficient for scientifically - based conclusions.

In this paper, the author has analyzed the required number and size of specimens for two typical material classes. The paper points out that the results are directly related to the specific material properties under study, and that other materials should undergo similar analyses, if other properties are the experimenter's concern.

I. CONSIDERATION OF SPECIMEN SIZE

I.1 THEORETICAL CONSIDERATION FOR MECHANICAL PROPERTIES

The minimum size of a specimen depends upon the material properties to be measured, the material characterizations to be performed, and the number of properties and characterizations to be determined. If only one test is to be performed, for example, then the minimum size is that required to perform the test. If more than one test is to be performed, the specimen must be large enough to perform both tests, and so forth. Furthermore it must be pointed out that if several specimens are prepared and one test performed on each specimen, each test measuring a different property, then process variations must be taken into account, and enough specimens tested to obtain a distribution for each property measured. If a number of tests are performed on each specimen, then enough specimens must still be examined to obtain a distribution for each property, but it is obvious that the number of specimens required will be smaller than that required on a one test per specimen basis.

Specimens of tungsten produced by containerless processing will, for example, require measurement of fracture strength, ductility, and ductile-to-brittle transition temperature. Materials characterization will include purity, gas content, grain size and shape, and homogeneity of microstructure throughout the specimen produced. This is a total of 8 primary factors to be determined. The most important of these for X-ray target material are the three engineering tests of ductility, fracture strength, and ductile-to-brittle transition temperature. These are the tests which show whether or not the service properties have indeed been enhanced by the process. Materials characterization (the five characterizations above) is required to explain the results of the engineering tests.

Tensile testing is required to determine the fracture strength, ductility, and ductile-to-brittle transition temperature of tungsten. The minimum size specimen required for tensile testing is a function of both the "size effect" and the practical limitations on

gripping specimens in a tensile testing device such as the Instron machine. Mechanical testing of materials which fail through brittle fracture show a dependence of strength on the size of the test specimen. As the specimen size decreases, the fracture strength increases. This is the "size effect".

A satisfactory model to explain the "size effect" in brittle fracture rests on the following assumptions:

1. Brittle fracture is controlled by a distribution of imperfections or cracks. For every size of crack, c , there will be a certain fracture stress, σ , given by the Griffith criterion, at which the crack will continue to grow. This criterion is

$$(1) \sigma_c = \left(\frac{2E\gamma}{\pi c} \right)^{1/2}, \text{ where } E \text{ is the Young's modulus and } \gamma \text{ the surface energy of the crack.}$$

2. Each specimen is made up of many volume elements which each contain a single crack.
3. There is no interaction between the cracks in different volume elements.

Under these assumptions, the strength of the specimen is determined by the volume element with the largest crack, since by equation (1) this results in the lowest fracture stress. The "size effect" therefore, is as follows: If the crack density of the material is assumed constant, as the volume of material increases, the total number of cracks increases. The probability of encountering a severe crack is thus, increased. As a result, as the specimen size increases, the fracture strength decreases.

Various distributions have been used to relate the fracture strength to the volume of the specimen (V). For a Gaussian distribution of cracks, the fracture strength decreases as $(\log V)^{1/2}$ increases. For Weibull's distribution the fracture strength

varies as $V^{-\frac{1}{m}}$, where m is the experimentally determined factor in Weibull's distribution. For a Laplacian distribution, the fracture strength decreases as $\log V$ increases.

With ductile metals, the size effect is not as large as in brittle materials. Plastic deformation changes the size and orientation of defects. The individual volume elements are no longer independent of each other. This poses an important problem for testing tungsten produced by containerless processing. The raw material is quite brittle, while the product is ductile if the process is successful. Good testing practice would seem to be to choose the same size specimen of raw material and processed material for comparison purposes. The selection of size for the specimen, then, is imposed by consideration of the raw material, assuming the processed specimen to be ductile. If the specimen size is too small, the fracture strength may be so high for the raw material as to make the comparison unsuitable for engineering application.

The suggested procedure here is to experimentally determine the relation between fracture strength and specimen volume for the raw tungsten material. This could be accomplished by testing ASTM standard dimension tensile specimens of various sizes down to the smallest that can be gripped in the tensile testing machine. The expected rise in fracture strength with decreasing specimen volume can be obtained then and a scaling factor determined. Specimen size would be selected on the basis of ratio of expected-fracture-strength to the theoretical-fracture-strength of the material were there no cracks at all.

This is very important when considering tensile test specimens made from centimeter-in-diameter specimens. The test specimens might be small enough in diameter to approach the theoretical strength of the material, as has been demonstrated with whiskers and fibers. In that case, the results of comparing the raw material with the processed

material would be that little, or no, difference exists, no matter what the differing characteristics were. Using Weibull's distribution:

(2) $\frac{S_1}{S_2} = \left(\frac{V_2}{V_1}\right)^{1/m}$, where S_1 and S_2 are the average fracture strengths of specimens of volumes V_1 and V_2 respectively. Although m for tungsten is not known, m 's of 25 or more have been observed for brittle fracture of steel at liquid air temperature. As m increases, the ductility increases so that for yield prior to fracture m values of 50 to 100 are uncommon. Choosing $m = 25$, then, typically consider a cylinder of dimensions 10 cm in length and 1 cm in diameter, versus a cylinder 1 cm in length by 0.1 cm in diameter. The respective volumes are 7.854 cm^3 and $7.854 \times 10^{-3} \text{ cm}^3$ respectively and letting $V_1 = 7.854 \times 10^{-3} \text{ cm}^3$ and $V_2 = 7.854 \text{ cm}^3$

$$\frac{S_1}{S_2} = (10^3)^{1/25}, \text{ or } \frac{S_1}{S_2} = 1.32. \text{ If there is no plastic yielding at all}$$

$$m \approx 6, \text{ then } \frac{S_1}{S_2} = 3.16.$$

Below the brittle-to-ductile transition temperature, tungsten is very brittle and has virtually no ductility, so this last figure is probably more realistic. Using the Weibull distribution, however, it can be seen that on a theoretical basis a small specimen that can yield a test specimen of 1 cm long by 0.1 cm in diameter could be tested to fracture and exhibit a fracture strength as high as a factor of 3 from the larger specimen. Since the theoretical fracture strength of metals is from 10 to 100 times the observed fracture strength of standard ASTM 2" gauge length specimens, the fracture strength observed in the small tensile specimen of raw material might compare favorably with that produced by space processing, while with standard 2" gauge length specimens, the enhancement produced by the space processing might be readily observed.

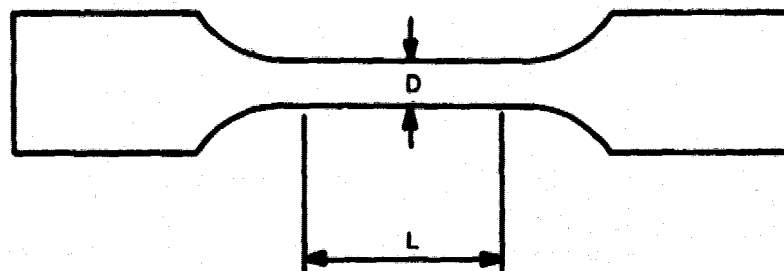
On the basis of the above analysis, it can be seen that specimens as small as one centimeter in diameter would not yield specimens that conclusively establish enhancement of service properties due to the size effect. A minimum specimen size of at least 2 inches in diameter would be required. Even this size will yield a reduced gauge length specimen since the specimen must be gripped in a tensile testing machine.

This does not imply, however, that useful data cannot be obtained from specimens as small as one centimeter in diameter. For example raw specimens and processed specimens can be rolled, and the reduction in height and flattening observed. This would establish a trend of enhanced ductility, which would be verified by testing larger specimens later. Characterization of grain size and shape, purity, residual gas content, homogeneity would all establish a trend toward greatly enhanced service properties. What the above analysis implies is that, for establishing service property enhancement, the larger the specimen, the better. It also implies that for brittle materials with $m \approx 6$, a lower limit of one centimeter in diameter could be established. Below this, the strength rapidly approaches the theoretical limit.

Where mechanical properties are not important, the above analysis does not apply. For transparent metal oxide glasses, for example, what is sought is production of a glassy phase, not enhancement of ductility. Here the minimum size necessary for characterization determines the minimum specimen size and this is discussed in Section I.3.

I.2 PRACTICAL CONSIDERATIONS FOR MECHANICAL PROPERTIES

The minimum size of a specimen is determined by the type of tests to be performed. Consideration of the mechanical properties of metals and alloys, for example calls for specimens from which test specimens can be fashioned which are of prescribed size and shape. Consider the tensile test. Here a cylindrical specimen is required, having a cross section as shown below.



This specimen must be of a size that fits the grips used with the particular test machine. For very small specimens, special grips or techniques for holding the specimen in the tensile test machine must be designed. With specimens as small as 1 cm in length, this can be a considerable problem.

In the United States, the standard tensile specimen has a diameter, D , of 0.505 inches and a gauge length, L , of 2 inches, so that $L/D \approx 4$. In Britain, $L/D = 3.54$, while in Germany $L/D = 10$. When comparing elongation measurements of different sized specimens, the specimens must be geometrically similar. Also, when experimentally determining the stress - strain curve for a material, the specimens must be geometrically similar. In that way, such factors as the size effect can be determined using standardized geometry. Since small specimens will initially be obtained in space processing experiments, it is important to consider just what size tensile specimens can be produced. Considering some ASTM tensile specimens below, we find that specimens as small as $D=0.160$ inches and $L=0.634$ inches are commonly used.

One must consider, however, that L is the gauge length and not the total length. Depending on the gripping techniques, even the smallest specimen here can have a total length in excess of 1.5 inches and a maximum cross section at the end pieces in excess of 0.5 inches. A rule of thumb commonly practiced is that the length between the enlarged ends is about $(L + D)$ long so that this length would be .794 inches for the smallest specimen listed in Table I.

TABLE I. ASTM TENSILE SPECIMENS

D, Inches	L, Inches	L/D
0.505	2	3.97
0.357	1.4	3.92
0.252	1.0	3.97
0.160	0.634	3.96

Consider now the effect of reducing the tensile test specimen diameter above. At $D = 0.160$ inches or 0.4064 cm, a material having an average grain size of one millimeter or 0.1 cm would have an average of 4 grains across its cross section. If the average grain size were 1 micron or 10^{-3} cm it would have 4064 grains across it on the average. For the one millimeter grain size specimen the standard gauge length specimen of $L = 2$ inches, $D = 0.505$ inches would have an average of 12 grains across it and the one micron grain size specimen an average of 12,000 grains. It is obvious that for the very large grained specimen, the smallest tensile test specimen considered here is of dubious value. With only four grains across it, the fracture stress will be higher because there is less chance of initiating crack propagation.

Even the standard gage length of 2 inches has only 12 grains across it! Reducing the gage length of the large grained specimen now to 1 centimeter in length (0.254 inches) would mean $D = 0.072$ inches or 1.82 millimeters. This specimen would have an average of only one or two grains across it. The fracture strength measured might be that of the single crystal material itself rather than the polycrystalline material. The small grained material would still have 182 grains across it and would still constitute an acceptable test specimen for tensile testing.

We can sum up this discussion as follows: For fabricating a tensile test specimen there is, first, a practical consideration of the technique for properly gripping the material in the tensile test machine. For small specimens, special techniques,

dependent upon the material, must be devised. Neglecting this aspect, however, there is the question of the validity of the test. This can be partially resolved by considering the expected grain size of the material developed. For tungsten, produced by nucleation from a highly supercooled melt, grain sizes of the order of 1 micron or less can be obtained. In that case, tensile test specimens of 100 microns in diameter or larger would be reasonable specimens (1 mm or larger). The gage length could be 3.54 mm or larger, for a standard tensile test specimen. The length between the enlarged ends would then be about 4.54 mm ($L + D$). The enlarged mounting ends then have to be considered. If the maximum length of the specimen is 1 centimeter, this leaves only 3.54 mm for the enlarged ends or 1.77 mm at each end.

Special techniques of mounting would have to be considered, then, for specimens as small as 1 cm in diameter which would be used in tensile testing to fracture. These are a matter of art and experience. It cannot be categorically stated that specimens as small as 1 cm in diameter are not practical for testing. The decision depends on the tensile testing machine, the scientist performing the test, and the tensile specimen that can be extracted from the specimen. For such small specimens of tungsten, for example, electrical discharge machinery has been considered to extract a core out of the material less than 1 cm long. This specimen must be electro-polished, or chemically polished, as considerable damage is done to the surface of the core extracted in this manner. With such small specimens all such factors must be very carefully considered before claiming a valid tensile test.

From practical considerations it is again seen that a 1 cm diameter specimen is of doubtful value in obtaining credible mechanical properties evaluation. To arrive at a satisfactory solution, it appears that a spectrum of sizes, with 1 cm in diameter as the minimum size, is indicated. The smaller specimens of tungsten would be subjected to cruder mechanical testing such as rolling to establish a trend toward enhanced ductility and greater fracture strength. As specimens become larger, more credible mechanical tests would be performed to establish this.

1.3 REQUIREMENTS FOR MATERIALS CHARACTERIZATION

Consider a one centimeter diameter specimen of tungsten. This weighs 9.95 grams, or about 10 grams. For emission spectrography, about 2 grams are required, for vacuum fusion analysis and conductometric analysis, about 3 grams. The remaining piece can be sliced and used for metallographic characterization, X-ray diffraction, and microhardness testing.

Thus, experience on our tungsten contract has shown that a one centimeter specimen is sufficient for materials characterization. No material is left for mechanical testing from this specimen.

The transparent metal oxides have a density of about 8 grams/cm³. A one centimeter diameter specimen would have about 4.2 grams of material. This would not be sufficient for all of the above tests, since this is required for emission spectroscopy and vacuum fusion analysis alone. Nothing would be left for metallographic examination, X-ray diffraction, thermal differential analysis, and other tests which would be performed to establish a glassy phase. A two centimeter diameter specimen would weigh 33.6 grams, however, which would be sufficient for materials characterization. Since no mechanical testing is contemplated, this would be an adequate size specimen for establishing whether or not a glass was produced.

It can be seen from these considerations that specimens of one to two centimeters in diameter are adequate for materials characterization. Thus experiments with such small specimens will yield useful data. Smaller specimens could not be completely characterized. The lower the density, the larger the specimen if emission spectroscopy, vacuum fusion and conductometric analysis, and differential thermal analysis are considered. For metallographic examination, X-ray diffraction, electron microscopy, etc. much smaller specimens can be considered than one centimeter in diameter. Based upon the above consideration of complete characterization for a specimen, most

materials require a 2 cm in diameter specimen, while some, like tungsten, require a 1 cm in diameter specimen.

It is of course, obvious, that the larger the specimen, the better it can be characterized. A specimen larger than the minimum size discussed above presents more material for characterization and hence more accurate determinations. Larger specimens also present the variability to be expected in actual commercial size products. Thus a spectrum of sizes with lower limit 1-2 cm in diameter should be considered. As size increases the characterizations approach what is to be expected in the commercial product.

I.4 SUMMATION OF MINIMUM SIZE OF SPECIMEN

If complete materials characterization and acceptable mechanical testing must be obtained out of one specimen, then the minimum size is about 7 centimeters in diameter. If only materials characterization is required, then 1 to 2 centimeters in diameter is adequate. A spectrum of sizes from the minimum size up should be considered reaching to the size required for commercial products. This would enable variability-of-product-with-size to be considered, and tend to greater accuracy and acceptance by industrial scientists and engineers.

II. THE NUMBER OF SPECIMENS

II.1 FREQUENCY DISTRIBUTION

For each property measured, or characterization performed, a frequency distribution is required. First, the process parameters for each specimen produced should be as nearly identical as possible. Next, the observations must be arranged into equal class intervals. Then the frequency of observations falling into each class interval can be determined, and a frequency histogram constructed. For example, grain size observations might be categorized into class intervals 1 - 100 microns, and so on - up to a millimeter in diameter, then 10 equal class intervals might be considered. Finer class intervals could also be considered, as desired.

For a given frequency distribution, the data extracted might be:

1. average value
2. observations which occur most frequently (mode)
3. the middle value of the observations (median)
4. the range (difference between largest and smallest observation).

From the frequency histogram the type of probability distribution can be determined. However, it may not be determined if it is not a normal or Gaussian distribution. Tests of significance can now be made. One such test is the F test given by

$$(3) F = \frac{S_1^2}{S_2^2}, \text{ where } S_1 \text{ is the standard deviation for a sample size } n_1, \\ \text{and } S_2 \text{ that for sample size } n_2 \text{ (where } n_1 \text{ is the number of observations} \\ \text{in the } i\text{'th population}).$$

Depending upon the results of the F test, the difference between the two means of the populations is determined.

Actually, the number of specimens required depends very much on the dispersion or scatter in the result obtained. If the first six specimens of tungsten all had an average grain size between 1 to 10 microns, then a narrow frequency distribution would be expected. Practically, the decision upon how many specimens to sample is a sensitive function of the scatter obtained in the data of the first few samples. If the variance is initially large, a large number of samples is indicated. As the population increases, the variance will approach a fixed number and a large enough population has been obtained.

If all the observations fall into one interval, then a minimum of 6 specimens should be obtained, in the opinion of this author. If the first six observations, however, fall

into widely differing intervals, then enough specimens must be obtained for the variance to approach a limit.

This might involve hundreds of observations. It is also the opinion of this author that the mode (observations which occur most frequently) is of primary importance to the process engineer. Also, the difference between the total population and the number out of the population representing the mode is important (relative probability of obtaining the mode). If the number of observations having the value of the mode is small, then the experiment does not seem to be successful. Ideally, the mode, the median, and the average value should differ little, and the range should be narrow. This would allow a clear conclusion of the success of the experiment.

For each property or characteristic, a frequency distribution is required. Some may be narrow and some very wide. Where a number of different observations are obtained from a single specimen, the number of specimens should be that corresponding to the observation showing the widest variance, if all the types are equally important.

The above discussion holds for an observation where processing parameters or test conditions are held fixed (as best they can). If correlations are to be made with size, temperature, cooling time, etc., then regression analysis is required. This will depend upon the number of data points obtained as the variate or variates are varied over the given interval. Multivariate regression analysis would normally require hundreds of specimens. In such analyses performed by this author, data points numbering hundreds to thousands have been required.

Without belaboring the point, it can be said that the first step should be to determine the frequency distribution which has the widest variance for a property at fixed parameters. This gives the number of observations required at fixed parameters. Then the number of variates and the interval of variation for each should be considered. This will allow estimation of the number of samples required for a multivariate

regression analysis. It is the opinion of this author that more than a hundred specimens will normally be required.

III SUMMARY

Table II is a summary of the statistically significant size and number of specimens of Tungsten, as obtained from Space Processing experiments, for assessing the desired improvements in that material for X-ray targets.

**TABLE II. STATISTICALLY SIGNIFICANT NUMBER AND SIZE OF
EXPERIMENT SPECIMENS (TUNGSTEN)**

KEY CONSIDERATIONS AND CRITERIA	REQUIRED TESTING	MINIMUM SPHERICAL SPECIMEN DIAMETER	MINIMUM NUMBER OF SPECIMENS (AT CONSTANT PROCESSING PARAMETERS)	CONDITIONS AND ASSUMPTIONS FOR MINIMUM NUMBER
MATERIAL PROPERTIES: 1) DUCTILITY AT 293°K	REDUCTION IN HEIGHT (ROLLING)	1 CM	6 (PER SET OF PROCESSING PARAMETERS)	• FOR CONSTANT ROLLING CONDITIONS • REDUCTION IS SAME WITHIN $\pm 1\%$
2) DUCTILITY AND FRACTURE STRENGTH AT 293°K	TENSILE TESTING	5 CM	6 (PER SET OF PROCESSING PARAMETERS)	• FRACTURE STRESS AND % ELONGATION AT FRACTURE WITHIN 1%
3) DUCTILE TO BRITTLE TRANSITION TEMPERATURE	REDUCTION IN HEIGHT (ROLLING) AT 293°K TO 600°K EVERY 50°K (8 STEPS)	1 CM	48 (PER SET OF PROCESSING PARAMETERS)	• FOR CONSTANT ROLLING CONDITIONS AT EACH TEMPERATURE • REDUCTION IS SAME WITHIN $\pm 1\%$
4) DUCTILE TO BRITTLE TRANSITION TEMPERATURE	TENSILE TESTING AT 293°K TO 600°K EVERY 50°K (8 STEPS)	5 CM	48 (PER SET OF PROCESSING PARAMETERS)	• FOR CONSTANT CONDITIONS AT EACH TEMPERATURE • ELONGATION AND FRACTURE STRESS IS SAME WITHIN $\pm 1\%$
MATERIALS CHARACTERIZATION:	• PURITY • GRAIN SIZE AND MORPHOLOGY • CRYSTAL STRUCTURE • GRAIN ORIENTATION	1 CM	6 (PER SET OF PROCESSING PARAMETERS)	• FOR EACH SET OF PROCESSING PARAMETERS CHARACTERIZATION YIELDS SAME RESULTS

APPENDIX B
EMI MEASUREMENTS OF A TYPICAL RF LEVITATION SOURCE (DROP PACKAGE)
AND ITS IMPLICATIONS FOR A SHUTTLE EXPERIMENT
E. OKRESS

I. CONCLUSIONS

1. Relative to Conductive EMI Broadband Measurements* Via Current Probe Per MIL-STD-461A Specifications:

Even relatively low power (e.g., 50W) RF generators may tax the attenuation or insertion loss capabilities of commercially available power line filters though not their power capabilities, the limit being tolerable size and weight. For example, an unshielded drop package, belonging to L. Napaluch, was conductive EMI tested. It required 50W input and produced conductive EMI of 55db above a μ A at 200 KHz above specifications limit, for CE03 conductive test of the MIL-STD-461A Specification. To filter 55db at 200 KHz is a difficult task, since commercial (e.g., Erie) L-filter can provide only 35 db and above attenuation or insertion loss at 200 KHz and above to 1 GHz. Therefore, at least two such power line filters are required to satisfy EMI specifications. The detailed conductive EMI (without susceptibility tests and no noise injection) measurements and associated computations are filed in the B.U.S. file.

Since no EMI measurements were made beyond 50W or up to and above 25KW, the following comments are speculative. Nevertheless, it would be expected that much more power line attenuation would be required and that this would tax commercial power line filters in this power range. (e.g., Filtron high power line filter can provide as high as 100 db and above attenuation at 200 KHz to 10 GHz). Again filter power capability would be limited only by tolerable size and weight. Specific figures would

*See text for details and precautions. Narrow band measurements were not made but derived from the former.

only have significance for EMI measurement of a specific RF generator in the 25 to 50 KW range. Alternately, for order of magnitude information, some RF power generator firms may be solicited for their EMI measurement data and power line filter firms solicited for attenuation, and power capabilities as well as size and weights of their power line filters. This was not done for lack of time. All leads-power and otherwise into and out of the space processing chamber must be twisted and cover shielded, aside from being conductive line filtered adequately, of course. Shielded twisted leads can provide 60-75 db of attenuation at power frequencies.

2. Relative to Radiated, Magnetic (H) field, EMI measurements* Via Loop Antenna per MIL-STD-461A Specifications

The same drop package was used for broadband measurements. The radiated EMI was determined as 56 db above pT above specification limit, determined at 100 KHz. Therefore, it is necessary to attenuate at least this much to just meet specification requirements. To allow a reasonable margin of safety, about 70 db above pT is required of the chamber surrounding this EMI generator. To attenuate 70 db at 100 KHz requires either 22.5 mils of stainless steel or 3 mils of mu-metal shielding. Since the envelope of the space processing system would be made of stainless steel or higher electrical conductivity materials of considerably greater than 22.5 mils, no shielding problem would arise on this account, provided all permanent and removable port joints are continuously electrically connected and back attenuated by standard EMI practice. Attenuation at joints of removable parts may attain the order of 80 db with commercial EMI conductive rubber gaskets (e. g., Metex Gasket Design Guide ME-33, excerpts filed). Electrical connections must be positive by means of soldering, brazing or less desirably by means of serrated spring fingers backed by said conductive rubber gasketing, according to EMI practice. Grounding of the shielding of EMI sources is best made to the bare metal, which may then be corrosion resistant coated (e. g., by Anodize). A much less desirable ground connection may be made through

*See text for details and precautions.

Alodine, Series 1000 coatings on the shield, but not through an Anodize coating, because the latter is non-conductive. At much high power, than the 50W RF (unshielded) generator, which was subject to Radiated EMI measurements, corresponding more shielding would be required, depending upon the radiated EMI power emissions as a function of frequency with respect to specification limits. No measurements were made at higher than the 50W RF (unshielded) generator.

II. RELATION TO SHUTTLE EXPERIMENT

The foregoing information relates to the shuttle experiment to the extent of measurements and results discussed.

III. RELATIVE TO THE MIL-STD-1541 SPECIFICATIONS

This specification does not define the pick-up device to be used nor the distance at which measurements are to be made of the RF source. In MIL-STD-461A there are two magnetic field measurements methods - one at 1 meter, for a magnetic sensor, (but loop allowed by NASA in place of this sensor); and the other, with a 12.5 cm diameter loop at the RF source.

IV. EXAMPLE FOR FREQUENCY POWER FOR SPACE PROCESSING OF TUNGSTEN

As discussed in foregoing Section I, the Space processing chamber ought to provide ample RF shielding for structural/pressure requirements alone. This assumes that all leads-power to otherwise - into and out of the space processing chamber and appended components will be twisted and overall shielded and conductively filtered to the required degree. Also any non-metallic ports will have to be doubly (Faraday) screen shielded, in accord with standard NASA EMI specifications. Grounding of the chamber and its components must be direct and positive, as referred to in Section I and discussed in the text of this report.

Specific results of the required degree of conductive and radiative EMI filtering and shielding, respectively, for a specific RF generator contemplated for space processing of the indicated amount of tungsten can only be determined reliably from:

1. EMI measurements
2. From RF generator manufacturer's conductive and radiated EMI measurement results.

at the specified RF power to be used. The foregoing and text information and speculations are based only on low RF power (50W) conductive and radiated EMI measurements, due in part to the time and limited funds available.

V. RELATIVE TO THE ELECTRON - GUN AND ITS POWER SUPPLY AND CONTROLS

No conductive nor radiated EMI measurements were made. However, the gun, leads to and from it, its required power supply and electronic controls must be subject to conductive and radiative EMI measurements. The required power line filtering and RF shielding, as well as precautions, leads, joints, etc., referred to in section I and the text of this report would have to be incorporated. In any event, the power line filtering and RF shielding would be expected to be less of a problem than that expected with the high power RF generator.

VI. RELATIVE TO CONDUCTIVE EMI (VIA POWER LINES)

The appended broadband measurements data of conductive EMI were performed with CP105 clamp-on-probe with:

1. Resistive load at (-) 28 VDC
2. Drop Tower Levitation Package (with power supply) at
 - 28 VDC Power (~12A)
 - +28 VDC Power (~12A)

No EMI filters used on the package. Both electronics board and work coil system of said package unshielded.

The correction factors for current probe, Empire or Singer CP105, due to its frequency response have been entered at the discrete frequencies of the filed charts. Above 240 KHz this correction varies from 0.5 db to 0 db. This leaves very substantial response at ~100 KHz and 200 KHz to be shielded. Response at broadband signal at center frequency of 24 KHz is within 124 db above a μ A/MHz plus 10 db allowed by "Notices 3" of subject specification.

For narrow band conversions, from broadband measurements, at discrete frequencies, the amplitude db (BW correction factor) = $20 \log_{10} (1/BW * \text{receiver})$. This is to be subtracted from the broadband measurement data at the two discrete frequencies shown, to yield the narrow band db above a μ V/meter.

For a low input power line (e.g., 200 V, 1/4 ADC, 50W) to R. F. Generators, Erie L-filters provide 35 db attenuation at 200 MHz to 1 GHz in the power line.

For a high input power line (e.g., 250V, 100 ADC, 25KW and as high as 600V, 100 ADC) to R. F. Generators, Filtron line filters provide ≥ 100 db attenuation at 200 MHz to 10 GHz in the power line.

VII. RELATIVE TO RADIATED EMI

The MIL-1541 specification does not specify the size of loop nor the distance of measurements to be used. This is the reason that the Fairchild ALP10 (24"-25"D., 1 turn) loop was used at 1 meter distance from the EMI source (i.e. Drop Package) with Fairchild EMC25 receiver. So, conversion can be made by the customer to satisfy whatever specifications have to be satisfied.

*BW in MHz.

The appended broadband (db above $\mu\text{A}/\text{MHz}$) measurement data of radiative EMI were performed with the foregoing specified loop and distance, with:

1. work coil system axes perpendicular to the loop axis and with:
2. work coil system axis parallel to the loop axis. The receiver noise level is about 28 db above a $\mu\text{A}/\text{MHz}$ min. Fairchild EMC25 used for all EMI measurements.

For narrowband (db above $\mu\text{V}/\text{Meter}$) conversion (Receiver noise can attain 0db above $\mu\text{V}/\text{meter}$), broadband discrete frequencies can be converted to narrow band EMI levels. (For each band the corresponding BW can then be used to determine EMI), The amplitude, db (BW correction factor) = $20 \log_{10} (1/\text{BW} * \text{receiver})$ is to be subtracted from the broadband H field data at discrete frequencies, to yield narrow band, db above $\mu\text{V}/\text{meter}$, with respect to H field measurements, to determine:

1. db above pT use the appended loop antenna nomograph, Figure 1. Thereon, the RE04 MIL461 specification is indicated. For the RE01 see appended Figure 2, taken from MIL461 Specification.
2. Thickness of magnetic shield required to satisfy whatever specifications are under consideration, use appended nomograph, Figure 3. For electric component use appended nomograph, Figure 4.

An illustration of the procedure of processing the measured data, for this specific case, which is applicable to any other specific case, follows:

1. Relative to the Conductive EMI measurements:

- 1.1 Magnetic H field conductive measurements not specified in MIL-STD-461A specifications. This information is derived indirectly from the current (probe) measurements included herein.

*BW in MHz.

The correction factors for current probe, Empire or Singer CP105, due to its frequency response have been entered at the discrete frequencies of the filed charts. Above 240 KHz this correction varies from 0.5 db to 0 db. This leaves very substantial response at ~100 KHz and 200 KHz to be shielded. Response at broadband signal at center frequency of 24 KHz is within 124 db above a $\mu\text{A}/\text{MHz}$ plus 10 db allowed by "Notices 3" of subject specifications.

For narrow band conversions, from broadband measurements, at discrete frequencies, the amplitude db (BW correction factor) = $20 \log_{10} (1/\text{BW} \times \text{receiver})$. This is to be subtracted from the broadband measurement data at the two discrete frequencies shown, to yield the narrow band db above a $\mu\text{V}/\text{meter}$.

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1. Relative to the Conductive EMI measurements:

- 1.1 Magnetic H field conductive measurements not specified in MIL-STD-461A specifications. This information is derived indirectly from the current (probe) measurements included herein.

*BW in MHz.

METER INDICATION

FLUX DENSITY

FREQUENCY

10^6 +120 dB ABOVE μV

pT 10^9 +180 dB ABOVE pT

10

10^5 +100

10^8 +160

100

10^4 +80

10^7 +140

10^6 +120

10^3 +60

10^5 +100

10^4 +80

10^2 +40

10^3 +60

RE04 - MIL-461 SPEC.
BROADBAND LIMIT
MAGNETIC FIELD

1000

10^1 +20

10^2 +40

10^1 +20

10000

10 0

10 0

50000

10^{-1} -20

10^{-1} -20

10^{-2} -40

10^{-2} -40

Figure 1. Loop Antenna Nomograph

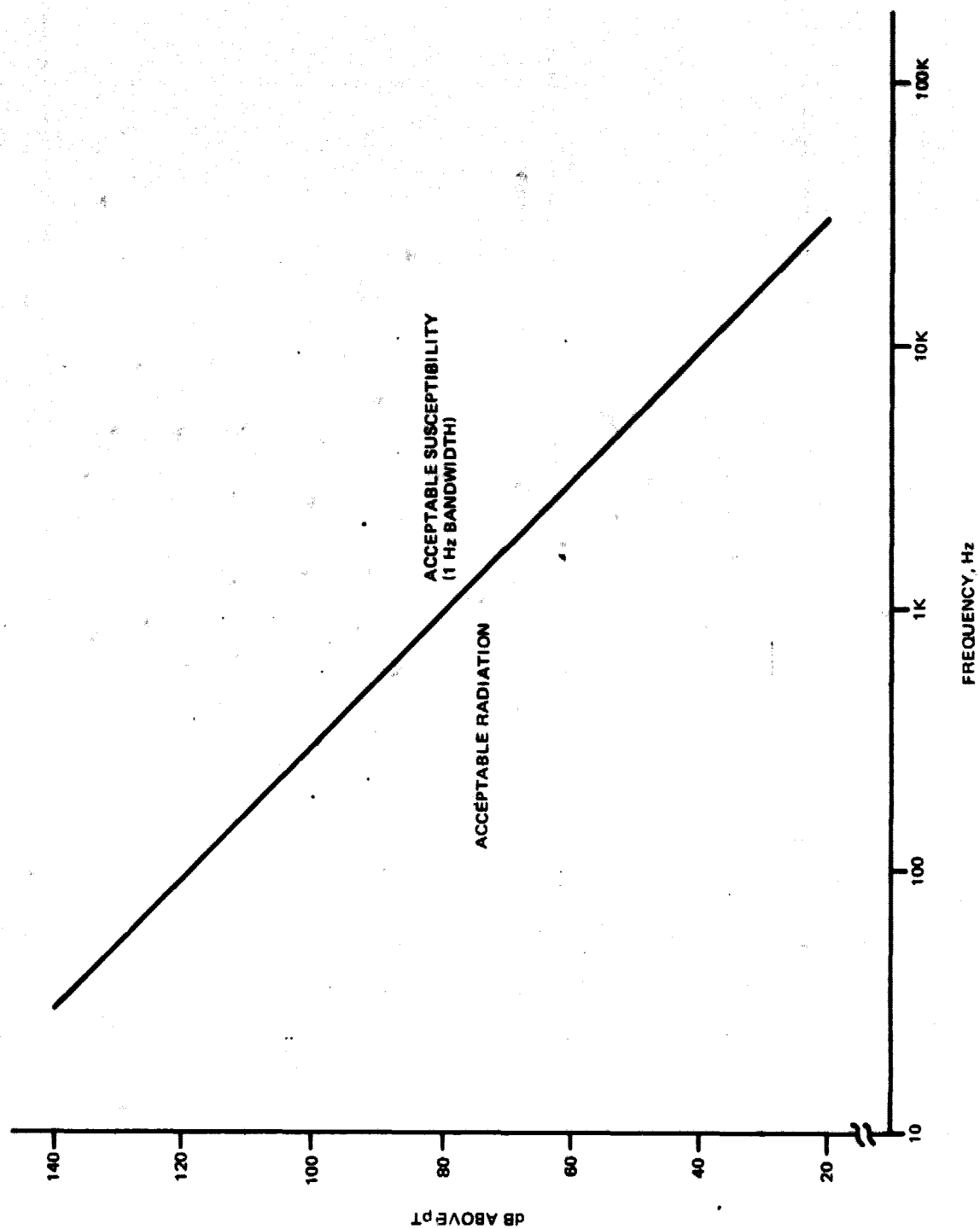
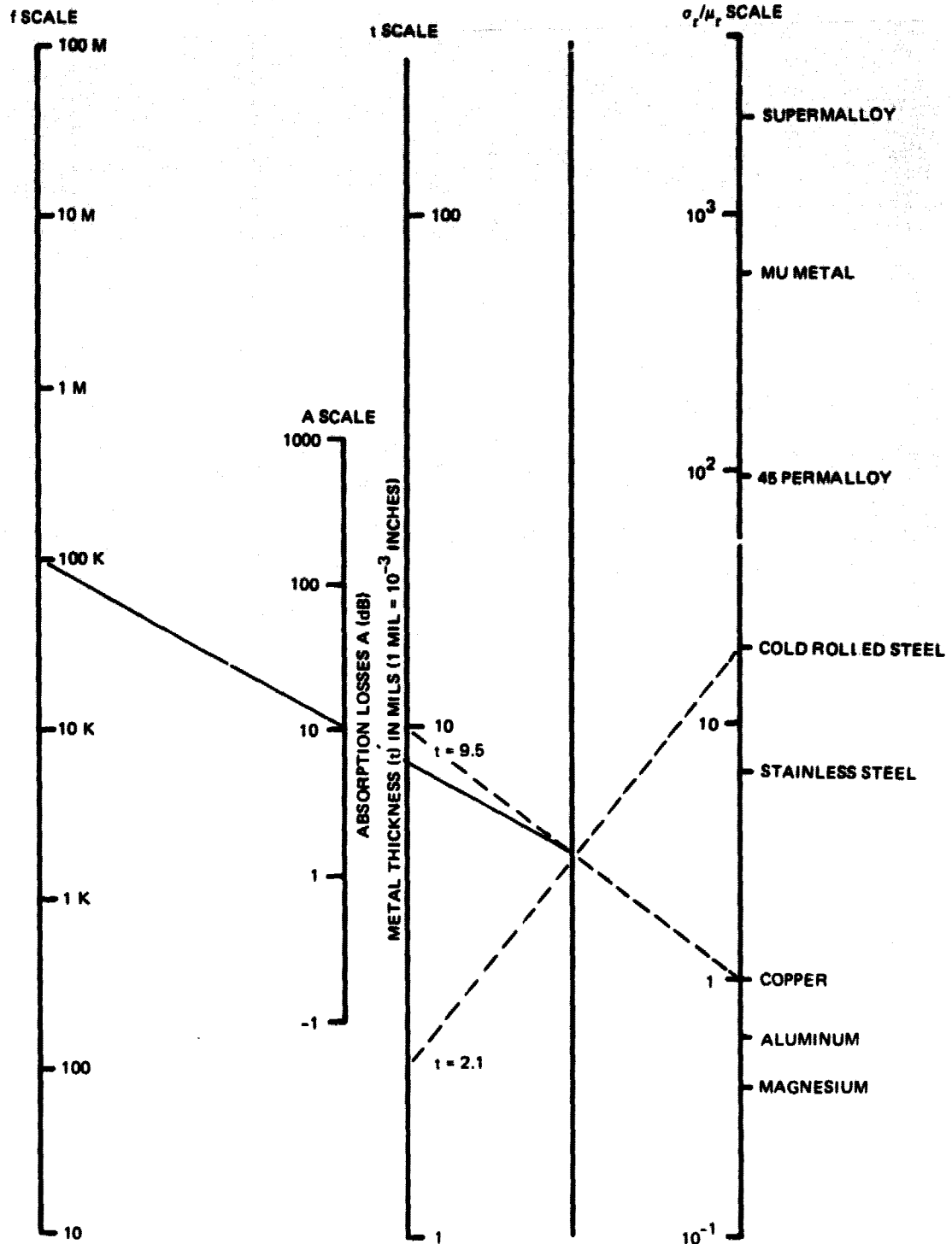


Figure 2. Limits for RE01 and RS01
Extracted from MIL-STD-461A

ABSORPTION LOSSES (A)



1) Locate frequency on f scale and desired absorption loss on A scale. Place straightedge across these points and locate point on the unmarked scale. (Example: $A = 10\text{ dB}$, $f = 100\text{ kHz}$.)

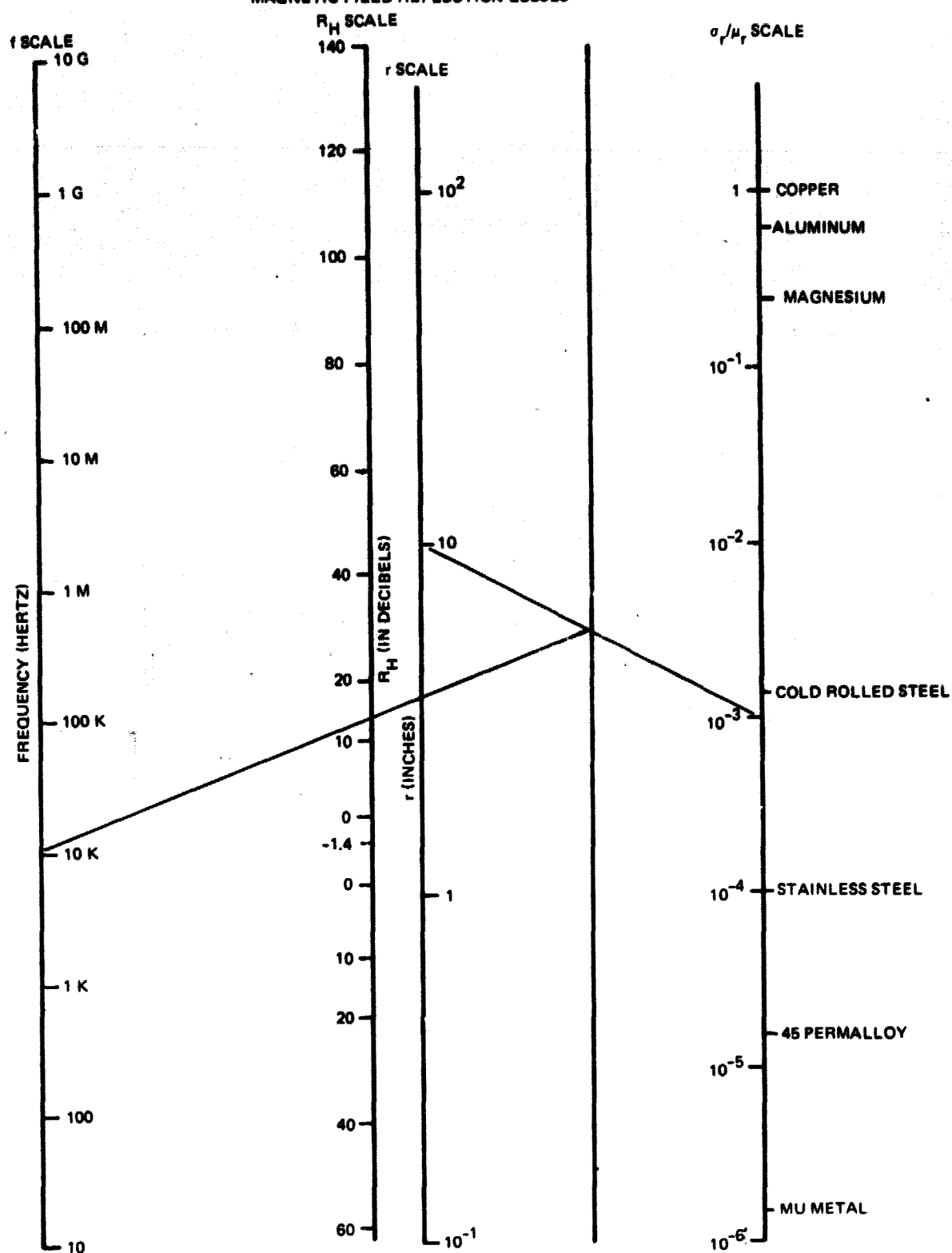
2) Pivot straightedge about point on unmarked scale to metals noted on the σ_r/μ_r scale. A line connecting σ_r/μ_r scale and point on unmarked scale will

give required thickness on t scale. (Example: for copper $t = 9.5\text{ mils}$, for cold rolled steel $t = 2.1\text{ mils}$.)

3) Absorption loss nomograph can also be used in reverse of the above order.

REF., R. COWDELL, ITT GILFILLAN

MAGNETIC FIELD REFLECTION LOSSES



- 1) Locate point on σ_r/μ_r scale for one of metals listed. If metal not listed, compute σ_r/μ_r and locate point on numerical scale.
- 2) Locate distance between energy source and shield on r scale.
- 3) Place straightedge between r and σ_r/μ_r and locate point on blank scale (Example: r = 10 inches for hot rolled steel).

- 4) Place straightedge between point on blank scale and desired frequency on f scale.
- 5) Read reflection loss from R_H scale. (For f = 10 kHz, R_H = 13 dB).
- 6) By sweeping f scale while holding point on blank scale, R_H versus frequency can be obtained. (For f = 1 kHz, R_H = 3.5 dB).

REF., R. COWDELL, ITT GILFILLAN

- 1.2 Electric, E, field conductive measurements are advantageous to do in order to save time and effort required to derive this data from the current probe measurements at discrete frequencies determined from magnetic field or derived from current probe measurements, herein. (E field measurements were not done at this time).

Comments:

- 1.2.1 The broadband (upper limits) specifications are linear from 135 db at 14 KHz to 50 db at 2 MHz and thereafter constant at 50 db to 1 GHz. See p. 10 of Notice 3 of MIL-STD-461A specification.
- 1.2.2 The narrowband (lower limit) specifications are linear from 80 db at 14 KHz to 20 db at 2 MHz and thereafter constant at 20 db to 1 GHz. See page 11 of Notice 3 of MIL-STD-461A specification.
- 1.2.3 Relative to filter power lines and whatever gets through shield power lines into filters by shielded twisted pair power lines, which yield the order of 70 db attenuation only for the electric, E, field. The power supply input impedance determines the type of power line filter to use. See pages 8, 9, 10, 11 from Erie Technological Products "Reference and Application Data" pamphlet. Notice that it is very difficult to achieve high EMI attenuation even with L type power line filters (p. 8 of cited pamphlet) at the lower frequencies of interest (e. g. , <200 KHz).
- 1.2.4 Relative to joints of shielding of EMI sources, said joints have to be carefully designed and fabricated. The ideal is continuous soldering or brazing of all joints. Alternately fastening together metal surfaces at frequent intervals along the seam is essential, either with bolts, rivets, etc., the spacing of which is dependent upon highest frequency components encountered.

according to standard EMI practice. Alternately conductive rubber is preferably inserted between the joints fixed or removable, yielding the order of 80 db EMI attenuation and is available. See Metex Corp. Gasket Design Guide ME-33.

It is important that no corrosion resistant coatings, such as "Anodize", which is a non-conductor, nor even "Alodine" of the 1000 series, which is conductive, be used between the joints of the shielding of EMI sources.

- 1.2.5 Grounding of the shielding of EMI sources is preferably made directly to the bare metal, which may then be protected with corrosion resistant coating such as "Anodize". A much less desirable ground connection to the shielding may be made through any "Alodine" series 1000 coating on the shield, but not through an anodize coating, because the latter is non-conductive as previously mentioned.
- 1.2.6 Relative to the thickness of the metal E-Field shielding to use, this is dependent upon the material and maximum frequency of significant EMI, (with respect to specifications). See Figure 3 Absorption Loss Nomograph. A reasonable margin of safety of metal thickness should always be used above the minimum indicated by said nomograph. For example, required 55 db at 200 KHz requires about 14 mils of stainless steel of about 1.6 mils of mu-metal.

1.3 CURRENT PROBE MEASUREMENTS PER MIL-STD-461A SPECIFICATIONS

A current probe correction has to be incorporated in the data reduction from these measurements, due to the response characteristics of the current probe as follows:

At 100 KHz a correction of +2 db above μA

At 200 KHz a correction of +1 db above μA , which has to be applied to the broadband measurements (in which case the correction unit is db above $\mu A/MHz$) and to the narrowband measurements (in which case the correction unit is db above a μA).

1.3.1 RELATIVE TO THE BROADBAND AMPLITUDE MEASUREMENTS:

This data may be used to derive the E-field specifications.

1.3.2 NARROWBAND AMPLITUDE MEASUREMENTS:

This data may be used to derive the E-field specifications. This data may be measured directly or derived from the broadband measurement data. A bandwidth correction factor has to be applied on account of receive response characteristics as follows

$$(db)_{corr} = 20 \log_{10} (BW)_{receiver}^{-1} \quad (BW \text{ in MHz}),$$

where the particular receiver bandwidth, as a function of frequency, has to be known.

The Broadband EMI measurements

Referring to the broadband power line conductive EMI measurements for ± 28 VDC Power Line as well as for a dummy load, two major peak amplitudes were evident.

Peak at 100 KHz amplitude 150 db above $\mu A/MHz$

At 100 KHz the narrowband MIL-STD-461A Specification limit is 58 db above μA (according to Figure 15, Notice 3 of the MIL-STD-461A Specifications).

The nominal BW of the receiver (Fairchild EMC25) at 100 KHz is 4KHz (according to Table 1.1 of the Fairchild EMC25 Receiver manual) at 3 db points. Hence, the amplitude correction factor

$$(db)_{corr} = 20 \log_{10} (BW)_{receiver}^{-1} + (2 \text{ db})_{corr}$$

However, it is not necessary to evaluate the former because the worst case is the amplitude peak at 200 KHz, where the amplitude amounts to 154 db above $\mu\text{A}/\text{MHz}$. At 200 KHz the narrowband MIL-STD-461A specification limit is 50 db, (according to Figure 15 of Notice 3 of MIL-STD-461A specifications).

Since the bandwidth of the Fairchild EMC25 receiver at 200 KHz (see Table 1-1 of Fairchild EMC25 nominal) is also 4 KHz, the

Amplitude correction factor

$$\begin{aligned} (\text{db})_{\text{corr}} &= 20 \log_{10} (\text{BW})_{\text{receiver}}^{-1} + (1 \text{ db})_{\text{corr}} \\ &= 49 \text{ db above } \mu\text{A} \end{aligned}$$

But, the said receiver accuracies are within ± 1.5 db of amplitude which will have to be applied to the $(\text{db})_{\text{corr}}$ computed as 49 db above μA .

Hence, at 200 KHz (worst case)

$$\begin{aligned} &\text{Peak at 154 db above } \mu\text{A}/\text{MHz (broadband)} \\ &\quad - 49 \text{ db broadband correction factor} \\ &\quad \hline &105 \text{ db above a } \mu\text{A (narrow band)} \end{aligned}$$

The MIL-STD-461A Specification has no limit on conductive EMI relative to the magnetic H field component. According to Figure 14, Notice 3 of MIL-STD-461A specifications at 200 KHz the limit is 50 db above μA .

So, the unshielded levitation Package is $105 - 50 = 55$ db above μA above the specification limit for CE03 conductive test of the MIL-STD-461A specification.

To filter 55 db is a difficult task at 200 KHz. For example, for an L-type filter Figure 2, page 8 Erie Technological Products "Reference and Application Data", only 35 db attenuation for insertion loss is introduced. Thus at least two such L-type power line filters are called for at low power.

2. Relative To The Radiated Magnetic (H) Field Measurements

Use nomograph Figure 1 Loop Antenna Fairchild ALP 10 with all corrections accounted for, for converting db μ V to db above pT.

For the broadband measurements, MIL-STD-461A specifications cite a limit of 60 pT from 30 Hz to 50 KHz, whereas measurements extended to 25 MHz. At 100 KHz measurement yields 115 db above μ V/MHz.

Due to lack of time, no E-field measurements could be made nor any narrowband H-field measurements. So, it is necessary to convert from broadband measurements to narrowband, as follows:

$$\text{Since } (db)_{\text{corr}} = 20 \log_{10} (BW)_{\text{receiver}}^{-1} \quad (BW \text{ in MHz})$$

Now the Fairchild EMC25 Receiver at 100 KHz has a broadband bandwidth of 4 KHz (WB) as measured, peak amplitude. So, $(db)_{\text{corr}} = 20 \log_{10} 250 = 48$ db above μ V correction factor to be subtracted from the broadband reading for 4 KHz bandwidth. (For 500 Hz (BN) bandwidth measurement, the correction factor would amount to 66 db or 66db-48 db = 18 db lower).

At 100 KHz, the broadband peak amplitude is 115 db. Subtracting the (db) correction from the latter yields a narrowband amplitude correction of 67 db above a μ V.

According to Figure 1 Loop Antenna Nomograph 67 db above a μ V corresponds to 116 db above pT. Hence, the MIL-STD-461A specification limit is 60 db above pT.

Therefore, 116 db above pT minus 60 db above pT per specification yields 56 db above pT above specification limit. Referring to Figure 3, Absorption Loss Nomograph, at 100 KHz and 70 dB attenuation, 22.5 mils of stainless steel or 3 mils of mu-metal is required. Any viewing ports must be doubly (Faraday) screened. Therefore it is necessary to attenuate at least this much to just meet the specifications. To allow a reasonable margin of safety 70 db above pT is required attenuation of chamber surrounding this EMI source.

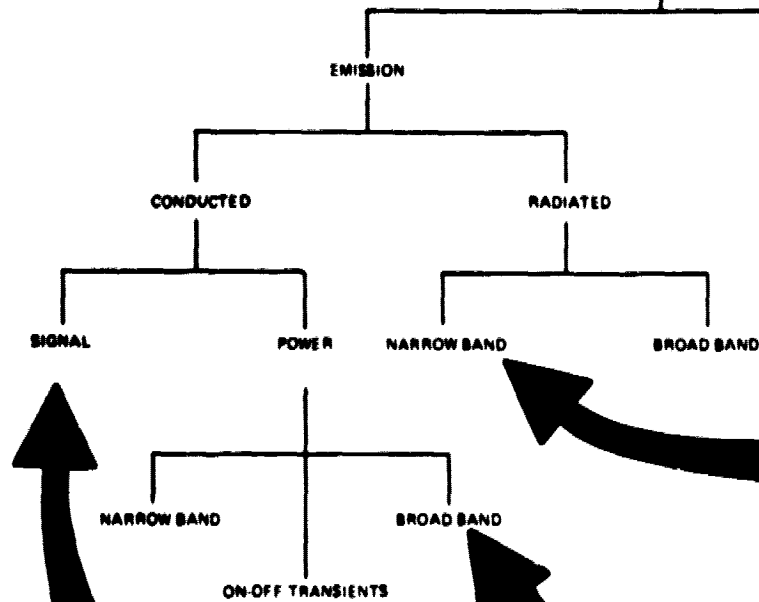
VIII. SUMMARY

Figure 5 summarizes the elements of Electromagnetic Interference and Susceptibility and displays the measurements made for this analysis against the MIL-STD limits.

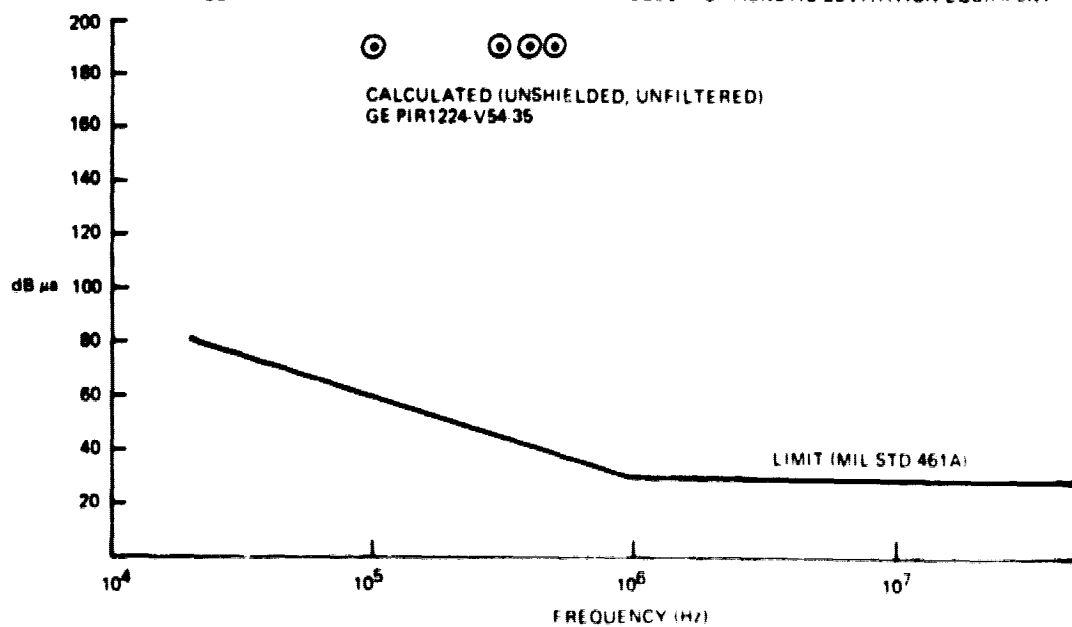
ELECTROMAGNETIC INTERFERENCE CHARACTERISTICS
REQUIREMENTS FOR EQUIPMENT FOR THE SPACE SHUTTLE
PROGRAM. MIL-STD-461A

ELECTROMAGNETIC COMPATIBILITY REQUIREMENTS
SYSTEMS FOR THE SPACE SHUTTLE PROGRAM
MIL E-8061D

ELECTROMAGNETIC COMPATIBILITY REQUIREMENTS
FOR SPACE SYSTEMS. MIL-STD-1541 (USAF)



CONDUCTED NARROWBAND EMISSIONS FROM ELECTROMAGNETIC LEVITATION EQUIPMENT



FOLDOUT FRAME 1

COMPATIBILITY REQUIREMENTS,
SPACE SHUTTLE PROGRAM

COMPATIBILITY REQUIREMENTS
MIL-STD-1541 (USAF)

SUSCEPTIBILITY

dB μ V/M

RADIATED NARROWSBAND EMISSIONS FROM ELECTROMAGNETIC LEVITATION EQUIPMENT

DATA DERIVED
FROM BROADBAND MEASUREMENTS
(UNSHIELDED, UNFILTERED)

LIMIT (MIL-STD-461A)

FREQUENCY (MHz)

CONDUCTED BROADBAND EMISSIONS FROM ELECTROMAGNETIC LEVITATION EQUIPMENT

MEASUREMENTS (UNSHIELDED, UNFILTERED)
GE PIR1224-V54-35

LIMIT (MIL-STD-461A)

FREQUENCY (Hz)

Figure 5. EMI Measurements, Limits and Categories

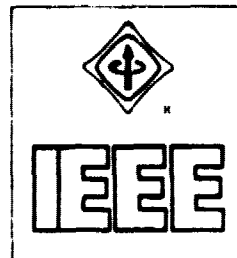
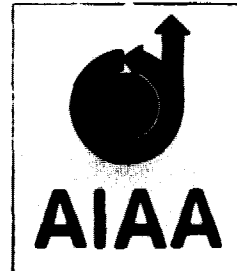
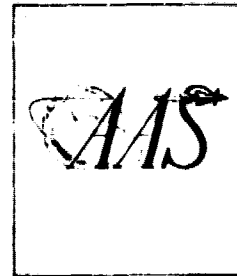


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Denver, Colorado
August 26, 27, 28, 1975



"THE INTEGRATION OF COMMERCIAL PAYLOADS INTO SPACE LAB"

Harold L. Bloom* and Kenneth R. Taylor†

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"THE INTEGRATION OF COMMERCIAL PAYLOADS INTO SPACELAB"

Harold L. Bloom* and Kenneth R. Taylor†

ABSTRACT

Paper utilizes results of three-year "Study for Identification of Beneficial Uses of Space" to project potential problems in integrating commercial payloads into Spacelab. Specific examples from this NASA-funded study are given to illustrate these problems, and to suggest some potential approaches for arriving at solutions.

Past and current studies are assumed to address "standard", general integration problems, and paper is, therefore, restricted to three areas of major concern to commercial Users:

- Industrial security - the protection of proprietary rights during pre-flight preparation, in-flight operations, and post-flight data and material handling.
- Costs and charges - the assurance of equitable allocation of STS costs among payload Users, and a mutually satisfactory schedule of User charges for recovery of those costs. Related concerns include insurance, indemnification for delays, accidents, changes, etc.
- Plans, schedules, decisions, priorities - the recognition that the relative flexibility in the timing of purely scientific research is not tolerable in the development of commercial products, and that the planning and scheduling of Spacelab payloads must account for the timing of key data necessary to decisions for carrying forward such development.

As a result of interactions with potential Spacelab Users, authors note actions and measures which may aid in easing such integration problems.

*Advanced NASA Programs, Space Division, General Electric Co.

†Applications and Technology, Marshall Space Flight Center, NASA

Planning for payloads in the Shuttle Era Space Program now includes a significant number of User-derived experiments and tests forming significant links in the development of specific commercial space processes and services. Typically, (Ref 1) analyzes the development needs (Fig. 1) for four commercial products based on space processing, and concludes that those needs will require Spacelab payloads on 18 Shuttle flights. In yet another discipline, (Ref 2) identifies dozens of commercial earth resources missions and defines the in-depth developmental and operational needs for one, Mineral Exploration (Fig. 2), which calls for about 10 Spacelab flights. These early indications of commercial payload utilization of Spacelab presage a potential wide-scale, broad spectrum of commercially oriented Spacelab payloads providing earthbound Users with a wide variety of benefits - and incidentally, providing the Spacelab/Payload integrator with a host of problems.

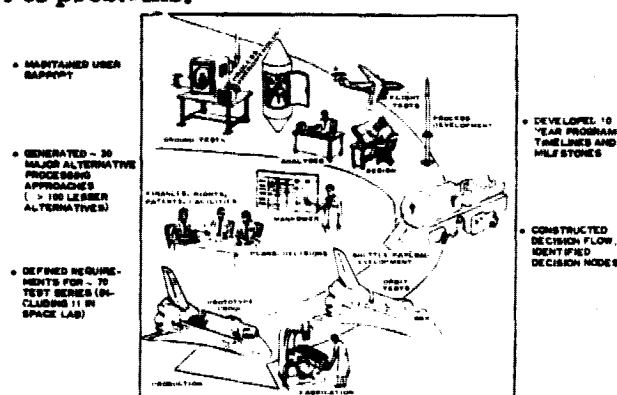


Fig. 1 B.U.S. Phase II Results

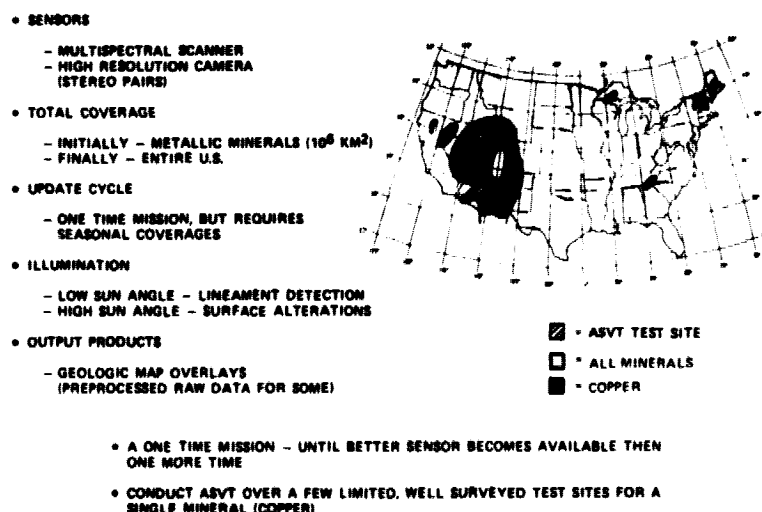


Fig. 2 Mineral Exploration - Mission Requirements

Historically, space program payload integration has necessitated resolution of such classical problems as payload accommodation size and weight constraints vs payload physical characteristics, matching of payload carrier power and thermal dissipation capabilities vs payload required peak and average power and energy output, analysis of adherence to safety standards, etc.

To such problems, the advent of commercially-oriented payloads adds new problems, and adds new dimensions to historical problems.

Review of the factors involved in space commercial enterprises (Fig. 3) identified in the study documented in Ref 1, quickly establishes that the root of these new and expanded problems lies in economics. In particular, key economic aspects that appear to affect integration of commercial payloads into Spacelab fall into three categories:

1. Industrial Security (competition, patents, anti-trust, etc.)
2. Cost and Charges (financing, plants, space launch & transport, liability, etc.)
3. Plans, schedules, decisions and priorities (space launch and transport, development, etc.)

This paper has been developed to identify the relevant payload integration facets in each of these categories, and to suggest some solutions to the problems they pose.

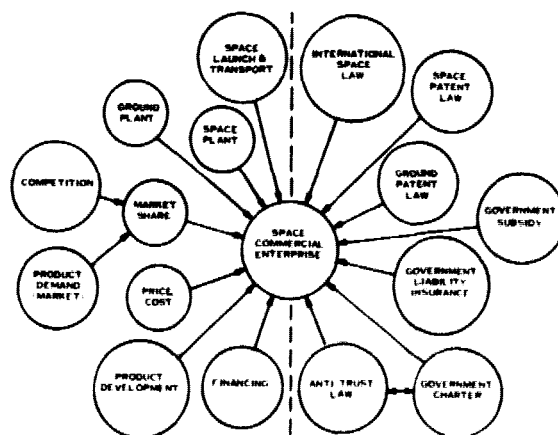


Fig. 3 Factors Involved In Space Commercial Enterprise

INDUSTRIAL SECURITY

The simplified title of this category of economic aspects belies the complexity of problems it encompasses. As one example, it is here that the potential space enterprise entrepreneur reflects his concern over maintaining the exclusivity of his product or service. Since in many commercial areas, a 6-month-to-a-year lead in developing a new product can spell the difference between a profitable business and a lost investment, potential Spacelab commercial User organizations tend to place emphasis on proprietary rights, patents, roles of various involved parties, etc. That emphasis is typically reflected in three of the questions noted in Fig. 4, which were asked by many participants in Phase I of the Beneficial Uses of Space Study (Ref 1). As early as fifteen years ago, such free enterprise concerns were expressed by then Chairman of the Board of General Electric, Ralph Cordiner (Ref 3) in his lecture on Peacetime Uses of Space:

"Testimony before Congress indicates that under the policy of uncertain patent protection, companies have been hesitant even to accept contracts for space projects that have interesting commercial possibilities. The witnesses made this point: If a company had invested much of its time and money in developing a certain technology, is it realistic to expect the company to liquidate this investment by turning its knowledge over to its competitors by way of the Space Agency?"

HOW WILL NASA HANDLE MY PROPRIETARY DATA (OR EQUIPMENT)?
WHAT RIGHTS WOULD NASA RETAIN ON MY DATA (OR PATENTS, OR PRODUCTS)?
WHO PAYS FOR SPACE EXPERIMENTS (OR TEST, OR EQUIPMENT) TO DEVELOP MY PRODUCT (OR PROCESS OR SERVICE)?
WHAT ROLE DOES NASA (OR CE) PLAY IN PROGRAM SUBSEQUENT TO B.U.S.?
WHAT IS THE PROBABILITY THAT THERE WILL BE A SHUTTLE (OR SPACE FACILITY)?
WHEN DO DECISIONS TO GO AHEAD NEED TO BE MADE?
HOW MUCH WILL IT COST TO RUN AN EXPERIMENT OR OBTAIN FACILITY SPACE?

Fig. 4 Typical Questions

How do such questions and related economic problems of industrial security influence integration of payloads into Spacelab?

Primarily, it is a matter of balancing the minimal amount of proprietary information that the User is willing to disclose about his materials, phenomenology, process, equipment, designs, etc. against the payload details that the integrator feels he must know in order to establish intra-payload compatibilities, payload/Spacelab accommodation utilization, interface control, safety, etc.

While it is likely that covert industrial espionage will be adequately controlled by existing techniques, the commercial User is logically apprehensive about inadvertent compromise of his position. For example, when faced with the number and extent of integration functions through which his "brainchild" must pass, as exemplified by the simplified integration flow in Fig. 5, he must consider the many points at which key data are generated, the amount of such data that is recorded, and the potential flow paths those data can follow. The potential "leakage" of such data to competitors is a major source of worry. Furthermore, in both the depicted physical integration process, and in the precursor integration "paperwork," the User is likely to be concerned with those aspects of integration that are generally carried out in the name of "efficiency," "synthesis," "cost effectiveness," etc.

It is good planning, for instance, to seek to optimize Shuttle payloads, and therefore, to consider combining such requirements as power, thermal control, etc. for various payload elements. Typically, it may also be possible that, at least in early experiments, NASA may foster "sharing" of data where such a mode minimizes power usage, or the number of required flights. The flow of information required to make such determinations, and the release of resulting experiment output are the sources of potential User concern.

Finally, the security of a User's venture may also be violated during on-orbit operations. It is in this phase of a project that the actual space dependent functions take place that are key to the User's venture. Data or specimens or processes observed at this time reflect the most sensitive interests of the User,

and yet are likely to be least under his control. Telemetered data, televised observations, recorded information, all present sources of potential security compromises.

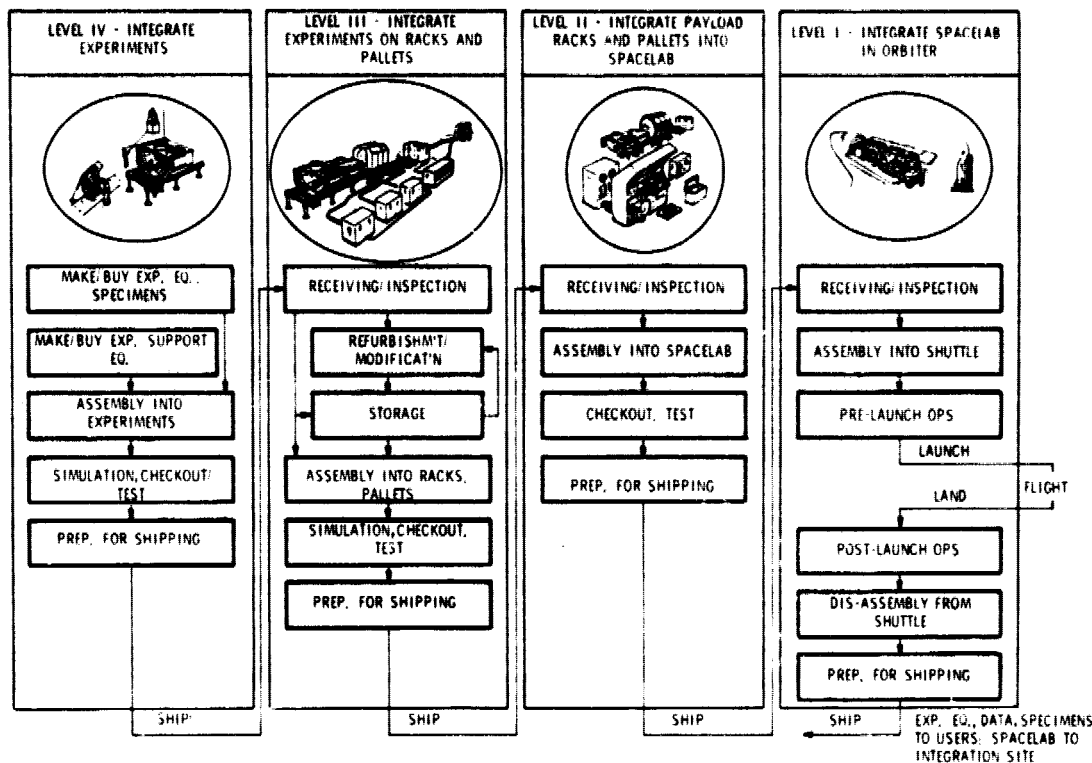


Fig. 5 Summary Payload/Spacelab/Shuttle Integration Flow

What can be done to reassure potential Users that their investments (dollars, time, expertise) will be protected in spite of the requirements imposed by integration of their payloads with other payloads, and into Spacelab?

In the long run, answers to this question will evolve from experience. For now, we list in Fig. 6 some possible approaches to reducing such concerns, and discuss some implications of these actions and measures. For example:

- Clear and more liberal regulations on patent ownership and rights-in-data will evoke wider commercial User interest, thus leading to an increased scope and spectrum of Shuttle payloads. The variety and quantity of such payloads will require an analogous variety and quantity of integration capabilities, many of which are likely to be considerably different from those involved in the usual aerospace programs.

Our studies indicate that early answers are needed here, in order to initiate comprehensive, User-backed payload studies. Fortunately, NASA has already recognized this need, and has the problem and possible solutions, under review. Furthermore, it is a fact that, in the Telstar program, for example, NASA did cede certain rights to the contractor.

- If NASA can allow the User to protect his commercial methods by relieving him of the need to develop certain data and/or to disseminate such data, the resultant reduction in integration paper work will be enjoyed, but the payload integrator will be faced with providing a higher level (e.g., rack or pallet) of risk protection, since details of lower level functions (e.g., sensor, processor) will not be available.

How to decide what the "proper" amount or type of disclosed data should be, will be a significant problem. Key guidelines for such decisions may possibly be derived from the experience of airlines or other transportation systems which frequently handle "sensitive" or dangerous cargo.

- Other actions and measures shown in Fig. 6 imply more and increasing difficulty of integration tasks, increased costs of integration tasks, decreased provision of on-orbit functions.

Costs and Charges

For commercial Users, Ref 4 points out that the expense of Space Operations will likely be critical to the profitability of their ventures. On that basis, potential Users will require realistic estimates of the costs of space operations, and the charges NASA expects to impose.

Where a User can expect to utilize a complete Shuttle payload capability, the cost of his operations is simply the cost of all operations involved in flying his payload. The problem becomes more complex when more than one payload is carried. In such cases, an equitable operational cost allocation among payloads is required, and a satisfactory schedule of charges by NASA for recovery of such costs.

USER CONCERNS	POTENTIAL APPROACHES TO REDUCE CONCERNS	IMPACT ON INTEGRATION	STATUS/REMARKS
PROTECTION OF PROPRIETARY METHODS DURING PRE-LAUNCH INTEGRATION ACTIVITIES	• LIBERALIZATION/CLARIFICATION OF NASA PATENT AND RIGHTS-IN-DATA REGULATIONS • RELAXATION/MINIMIZATION OF DATA ACQUISITION AND DATA FLOW FOR INTEGRATION • APPLY MILITARY/INDUSTRIAL-TYPE SECURITY SYSTEM • AUTOMATED, "SEALED" EQUIPMENT • MINIMAL DATA TRANSMISSION • SECURE COMMUNICATIONS	• MAJOR DRIVER OF NUMBER AND TYPES OF COMMERCIAL PAYLOADS TO BE INTEGRATED • INCREASES NUMBER AND TYPES OF REQUIRED CAPABILITIES • REDUCES PAPERWORK • INCREASES OPERATIONAL RISK PROVISIONS • INCREASES COSTS, TASK DURATION • INCREASES TASK DIFFICULTY • INCREASES RISK PROVISIONS • MINIMIZES PROVISIONS FOR ON-ORBIT MAINTENANCE, REPAIR • MINIMIZES COMMUNICATIONS PROFILING • INCREASES COST, COMPLEXITY	• REGULATIONS PRESENTLY UNDER REVIEW • NASA HAS CEDED RIGHTS IN SEVERAL CASES • FINAL DECISION NEEDED EARLY • WHAT IS "MINIMUM" DATA, "MINIMUM" FLOW? • PRESENT TRANSPORTATION SYSTEMS HANDLE SENSITIVE CARGO • DIFFICULT TO ENFORCE • RELATIVELY EFFECTIVE FOR NEEDED SHORT LEAD TIME • AUTOMATION IS NORMAL INDUSTRY MODE • REDUCES REAL TIME EXPERIMENT REDIRECTION • NORMAL FOR COMMERCIAL PRODUCTION • AVAILABLE TECHNIQUES
ON-ORBIT SECURITY			

Fig. 6 Potential Approaches for Reducing Typical User Concerns Over Commercial Payload Security

Accounting for the costs associated with Shuttle operations is, at present, a key task under intensive study by the NASA. A method of allocating that cost among payloads, however, has received little study to this time. Ref 1 has suggested such a method, and the method provides, in addition to the costing data, an aid to payload integration.

Briefly, the Cost Allocation Model of Ref 1 is based on the "resources" utilized by each payload, and allocates portions of total mission cost to each payload proportional to the portions of "resources" utilized. For purposes of this allocation, "resources" include payload bay volume, total allowable payload weight, on-orbit power etc.

As shown in Fig. 7, total mission costs are first reallocated to mission phases, weighted according to the degree to which that phase is important to payloads in general. The weighting is subjective, and, as other weightings shown later,

subject to change, as experience dictates. Reallocations to lower levels are then carried out as shown in Fig. 8, and rates established for the key resources in each mission phase, as typified in Fig. 9 and 10.

THE GENERAL EXPRESSION OF THE MODEL IS:

$$C_M = C_1 + C_2 + C_3 + C_4$$

C_M = TOTAL PER MISSION COST OF SHUTTLE OPERATIONS, AVERAGED

C_1 = PORTION OF TOTAL COST ALLOCATED TO UP-TRANSPORT PHASE

C_2 = PORTION OF TOTAL COST ALLOCATED TO ON-ORBIT PHASE

C_3 = PORTION OF TOTAL COST ALLOCATED TO DOWN-TRANSPORT PHASE

C_4 = PORTION OF TOTAL COST ALLOCATED TO GROUND OPERATIONS.

RECOMMENDED WEIGHTING:

C_1 = 45% OF C_M

C_2 = 22.5% OF C_M

C_3 = 22.5% OF C_M

C_4 = 10% OF C_M

Fig. 7 Recommended Shuttle Utilization Cost Model

THE COST EXPRESSION FOR THE UP-TRANSPORT PHASE IS:

$$C_1 = C_{11} + C_{12}$$

WHERE

C_{11} = PORTION OF C_1 , ALLOCATED TO UP-TRANSPORT VOLUME

C_{12} = PORTION OF C_1 , ALLOCATED TO UP-TRANSPORT WEIGHT

SINCE VOLUME APPEARS TO BE A GREATER PAYLOAD CONSTRAINT THAN WEIGHT, WE RECOMMEND

VOLUME $C_{11} = 60\%$ OF C_1

WEIGHT $C_{12} = 40\%$ OF C_1

Fig. 8 Cost Allocations for the Up-Transport Mission Phase

The complete suggested Cost Allocation Model is given in Ref 1.

But what has this to do with Payload Integration?

C_{11} AND C_{12} ARE FURTHER ALLOCATED AS FOLLOWS:

$$C_{11} = (V_{11} \cdot U_{11} \cdot R_{11})$$

WHERE

V_{11} = PAYLOAD BAY VOLUME CAPACITY (300 CUBIC METERS)

U_{11} = UTILIZATION FACTOR FOR UP-TRANSPORT VOLUME (PERCENTAGE)

(FRACTION OF PAYLOAD BAY VOLUME OCCUPIED BY PAYLOAD - CALCULATED ON YEARLY BASIS TO EVEN OUT VARIATIONS DUE TO FLUCTUATION IN AVAILABLE PAYLOADS AND IN ORBIT SELECTION)

R_{11} = COST RATE FOR UP-TRANSPORT VOLUME (DOLLARS PER CUBIC METER) (RATE IS SUCH THAT THE VOLUME V_{11} TIMES UTILIZATION FACTOR U_{11} YIELDS THE AVERAGE COST C_{11})

ALSO,

$$C_{12} = (W_{12} \cdot U_{12} \cdot R_{12})$$

WHERE

W_{12} = PAYLOAD BAY WEIGHT CAPACITY FOR UP-TRANSPORT (29,500 KILOGRAMS)

U_{12} = UTILIZATION FACTOR FOR UP-TRANSPORT WEIGHT (PERCENTAGE) (CALCULATED ON YEARLY BASIS)

R_{12} = COST RATE FOR UP-TRANSPORT WEIGHT (DOLLARS PER KILOGRAM)

Fig. 9 Cost Allocations for the Up-Transport Mission Phase (Continued)

IN PRACTICE, UTILIZATION FACTORS AT FIRST DERIVED ANALYTICALLY, LATER FROM OPERATING EXPERIENCE. PRESENTLY WE RECOMMEND:

U_{11} = 70% (VOLUME)

U_{12} = 60% (WEIGHT)

THE RATE FACTORS (R_{11} AND R_{12}) THEN DETERMINED AS FOLLOWS:

$$R_{11} = \frac{C_{11}}{(V_{11} \cdot U_{11})} = \frac{C_{11}}{300 M^3 \cdot 0.7} = 0.00476 C_{11} \text{ PER CUBIC METER}$$

$$R_{12} = \frac{C_{12}}{(W_{12} \cdot U_{12})} = \frac{C_{12}}{29,500 kg \cdot 0.6} = 0.000565 C_{12} \text{ PER KILOGRAM}$$

METHOD IS ANALOGOUS TO CURRENT CARGO TRANSPORTATION RATE ESTIMATING METHODS: FACTORS () NOT VARY FROM TRIP TO TRIP, RATHER, ESTABLISHED BEFOREHAND, CARRIED THROUGH GIVEN PERIOD, THEN ADJUSTED FOR LATER PERIOD WHERE EXPERIENCE DICTATES.

Fig. 10 Cost Rates for Up-Transport Mission Phase

First, a clear, equitable cost allocation method, coupled with a reasonable charge policy (Fig. 11) will encourage a large, broad spectrum of Users, thus requiring deep, broad integration capabilities.

- STS OPERATIONAL COSTS MUST BE RECOVERED OVER THE LONG RUN
 - CONSIDER YEARLY (OR LONGER) AVERAGING
 - CONSIDER DEFERRED RECOVERY (OUT OF PROFITS, ROYALTIES)
- NO MINIMUM CHARGE
 - IF SUBSTANTIAL, DISCRIMINATES AGAINST SMALL USER
 - IF MINOR, WHY BOTHER?
- CREATE OPPORTUNITIES FOR SHARING (DATA AND COSTS) - BROKERAGE
 - COMMERCIAL/COMMERCIAL USERS
 - COMMERCIAL/GOVERNMENT AGENCY USERS
 - GOVERNMENT AGENCY/GOVERNMENT AGENCY USERS
- EXPERIMENT PROGRAM CHARGES MUST BE COMPETITIVE WITH EXISTENT FACILITIES
 - GROUND FACILITIES ARE FAMILIAR
 - GROUND FACILITIES HAVE PRODUCED RESULTS, NOT JUST PROMISES
 - EARLY, INCENTIVE-TYPE CHARGES ARE STANDARD
- FLEXIBILITY NEEDED
 - USER EXPERIENCE TO UPDATE COST/CHARGE PROGRAM
 - ABILITY TO ACCOMMODATE NEW TYPES OF USERS, SERENDIPITY
- GOOD PR NEEDED
 - REVIEW RIGHTS, PATENTS POLICIES
 - SELL SPECIFIC BENEFITS - TO - USER

Fig. 11 Recommended Charge Policy Guidelines

More important, the suggested cost method provides incentives and dis-incentives for encouraging and/or discouraging use of Shuttle resources, so that a significant portion of the payload optimization effort, normally a part of payload integration, is carried out by the User. For example, on-orbit power is a resource which can be conserved by dis-incentivizing its use through judicious selection of high weighting factors. Users will then minimize their power use to minimize their power cost. Similarly, tradeoffs between weight and volume, astronaut time and automated equipment weight, etc. will be carried out by Users to minimize their costs; and, incidentally, contributing to maximizing of total-payload per-mission for the payload integration.

Other User concerns regarding costs and charges include the need for protection of investment via insurance of payload, the consideration that in commercial circles "time is money" and flight delays or schedule changes may call for indemnification of costs. In addition, the commercial User is particularly sensitive to potential liabilities incurred through accidents involving his equipment, and will seek to clarify the responsibilities and limits of such liabilities prior to committing to space activities. In all of these situations, the payload integration function will include primary responsibility for establishing, a priori, the boundaries (physical, functional, schedule, etc) that delineate responsibilities among payload entities, between payload and Spacelab, and between the User and the NASA.

In summary, then, STS cost and charge planning data needed by potential commercial Users will ultimately be reflected in the integration of Spacelab payloads. Fig. 12 lists some typical approaches in which such data may be developed, and how those data may affect the integration effort.

- Typically, as noted earlier, a cost allocation model (such as that suggested in Ref 1) which is based on STS resources and provides incentives and dis-incentives by weighting of allocations, will create an atmosphere for payload optimization at even the lowest level of integration. Such a trend will simplify the later levels of integration, and tend to optimize the overall STS utilization. Where experience shows greater (or lesser) use of a resource than desired, the model can be updated on a regular basis to achieve desired utilization.

USER PLANNING AREAS	POTENTIAL APPROACHES TO PROVIDE PLANNING DATA	IMPACT ON INTEGRATION	STATUS/REMARKS
COSTS OF SHUTTLE UTILIZATION	• ALLOCATION OF COSTS BASED ON RESOURCES USED • INCENTIVE/DIS-INCENTIVE WEIGHTING • RE-ALLOCATIONS BASED ON EXPERIENCE	• OPTIMIZATION BY USER SIMPLIFIES INTEGRATION • EARLY DECISIONS WILL LEAD TO EARLY NUMEROUS PAYLOADS TO SCHEDULE AND ACCOMMODATE	• SUGGESTED COST ALLOCATION MODEL DERIVED FROM PRESENT TRANSPORTATION INDUSTRY METHODS (INCENTIVES, RESOURCES USED, AVERAGING, ETC.) • USERS CONCERNS ALREADY IN EVIDENCE
	• AVERAGING OF SHUTTLE OPERATIONAL COSTS ON (AT LEAST) ANNUAL BASIS • AVERAGING ALL MISSIONS (HI, LO ALTITUDES, INCLINATIONS)	• INCREASES "ACCOUNTING" PAPERWORK • INCREASES COMPATIBILITY ANALYSIS EFFORT • MINIMIZES UNDER-UTILIZATION OF HIGH COST (HI ALTITUDE, HI INCLINATION) MISSIONS	
CHARGES TO USER	• EARLY DEFINITION OF OFFICIAL POLICY (SEE FIGURE 11) LONG RUN COST RECOVERY (EQUITABLE TO LARGE AND SMALL USER, ETC.)	• EARLY DECISIONS AND "ACCOUNTING" IMPLICATIONS, AS ABOVE	• WHAT IS "EQUITABLE"? IN MANY PRESENT SERVICE BUSINESSES, SMALL USERS SUBSIDIZE LARGE USERS.
	• "BROKERING" OF MISSIONS/ACCOMMODATIONS TO SHARE CHARGES	• "BROKER" MUST HAVE SOME INTEGRATION CAPABILITY • INCREASES COMPLEXITY OF USER/NASA INTERFACES AND RESPONSIBILITIES IN LEVEL III, II INTEGRATION	• "BROKER" IS IN VULNERABLE SPOT • NASA IS PRESENTLY "BROKER", BUT COMMERCIAL ASPECTS MAY NECESSITATE CHANGE
PROPERTY INSURANCE, INDEMNIFICATION FOR DELAYS, ACCIDENT LIABILITY, ETC.	• EXTENSION OF PRESENT COMMERCIALLY UTILIZED COVERAGES, AS MODIFIED BY NASA HISTORICAL PERFORMANCE	• ESTABLISHES, ALLOCATES BOUNDARIES OF RESPONSIBILITIES BETWEEN PAYLOADS, PAYLOAD/SPACE LAB	• COMMERCIAL COVERAGE MAY BE COSTLY. GOVERNMENT GUARANTEES HAVE PRECEDENTS

Fig. 12 Potential Approaches for Providing Typical User Planning Data on Shuttle Utilization Economics

- The suggested model was an outgrowth of current cargo transport practices, and represents judgemental estimates of relative mission phase importance, comparative availability of resources, etc for a Space Processing program. Considerable review of the model specifics is required before attempting its application to other programs.
- Charges, the method by which the NASA will recover the costs identified for each payload, bears extensive consideration. almost all potential commercial Users contacted to date have raised the question of charges early in discussions. If suggestions listed in Fig. 11 are amplified upon and followed, the potential Users will be numerous and will represent a cross-section of a major portion of basic commercial industries. This, in turn, will impose the need to integrate a large volume and a wide variety of payloads. Furthermore, the "bookkeeping" necessary to assure a viable charge system will be extensive.

If costs and charge quantities are defined as equivalent by the charge policy, then the only remaining question is how such monies shall be paid. Alternative payment modes include pre-flight or post-flight payment, payment out of profits, royalties to the Government, etc. On the other hand, either to encourage STS Users, or because payload results may have public benefits, NASA may elect to subsidize all or some of the costs. In such cases, more complex charge-policy regulations are required. In all cases, an equitable policy must serve to encourage the growth of a User community.

PLANS, SCHEDULES, DECISIONS, PRIORITIES

The heavy emphasis that our Space Program has, up to now, placed on scientific research missions has, to some degree, allowed more flexibility in the time-oriented project planning, scheduling, decision making, etc. than most commercial ventures can tolerate.

While, in general, our record for meeting launch windows and rendezvous times has been excellent, the multiplicity of potential STS and payload elements which must be integrated for anticipated future flights gives rise to User concern over the capability to maintain such continued successful timing. That concern is based on the necessity for timely blending of the plans for ground-based financial, technical, and production activities with those of space-based developmental activities in order to accomplish specific commercial User-defined programs on schedule. Timing becomes critical to the commercial User, both because of competitive pressures, and because invested "sunk funds" generate interest costs. Thus, commercial Users will require detailed STS and payload plans and schedules as well as timely decisions, for all operational and physical items with which their payloads must be integrated. Since on-time delivery of specified equipment or services is the lifeblood of a successful commercial business, such Users will undoubtedly be certain of meeting their planned and scheduled commitments, and will require assurance that the rest of the payload and STS elements will do likewise.

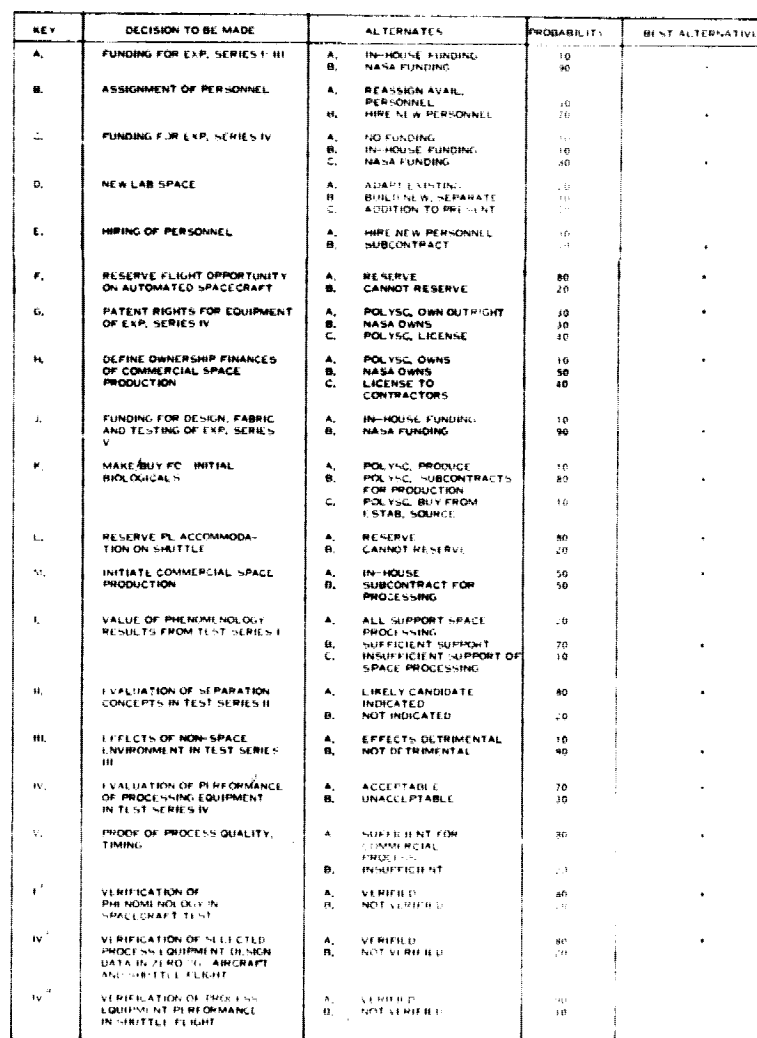
A primary impact of plans and schedules is felt in decision processes involved in proceeding with commercial ventures. Such decision processes which are composites of time-phased technical and administrative plans and schedules,

are typically represented by fig. 13, extracted from an earlier phase of the study reported in Ref 1. As exemplified in the Figure, technical and administrative decisions for commercial products are highly interactive, both in the alternatives for decision and in timing. Changes or delays in decisions are, therefore, sources of concern to commercial Users, since such changes or delays exert impacts throughout subsequent technical and administrative aspects of a program. Such a User is particularly sensitive to events just prior to, and subsequent to large financial outlays.

The planning of Spacelab payloads and traffic models responsive to the needs of scientists and industrial researchers, commercial organizations and Government agencies, universities and commercial laboratories, large users and small users, self-funded experimenters and those needing subsidies, etc. poses a major problem in priorities. Whose payload shall fly first, or earlier?

Various methods of prioritization of experiments and payloads for spacecraft have been developed and utilized in numerous studies and flight programs with varying degrees of success. Inclusion of commercial experiments in Spacelab, however, requires reassessment of such methods, and, will, no doubt, evolve new priority criteria. It is important to understand that the commercial community is realistic, and understands that experiments that can lead to improvements in public safety and health will acquire high priority ratings. Commercial Users will not so much seek the highest priority rating as they will seek a clearly defined, equitable priority system, which allows them to plan commitments for equipment, facilities and other resources. The solutions to much of these problems lies in adequately prepared, intelligently communicated, and competently carried out, plans and schedules.

NASA has demonstrated these capabilities in programs involving the aerospace community. Many of the same techniques utilized in those programs will apply in commercially-oriented programs, with some modifications. Typically, making the users a party to preparing program plans, and carrying out unambiguous two-way communication of requirements, accommodations, problems and solutions, apply equally well in the aerospace and the commercial communities.



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However, additional concepts and some new language centering on economics, (see for example, Fig. 14, from Ref 1) must be added to NASA's vocabulary. Moreover, an even greater transfusion of space concepts and language must be performed for commercial Users of STS. Bearing the brunt of resolving the problems of plans, schedules, many decisions, and priorities is a function of payload integration. Fig. 15, lists some typical solutions to these problems.

- The education process must be an activity of the payload integration function. Furthermore, the combined preparation of program plans and the two way communication mentioned earlier are first steps in the integration process.
- Within the mutually (User and STS) supportive plans and schedules, there will evolve the flow of required decisions. A major effort of payload integration will be to maintain cognizance of all decisions affecting each commercial payload program, to re-assess the effects of such decisions, and to communicate to all involved parties the subsequent program changes, where appropriate. In particular, those decisions, program effects and changes which impact investments are of primary importance to the commercial user.

CUMULATIVE CASH FLOW

- THE SUMMATION OF THE ANNUAL CASH FLOWS (INCOME LESS OUTGO) FROM INCEPTION TO CURRENT PERIOD, OVER THE CHOSEN FORECAST PERIOD

BREAKEVEN POINT

- THE POINT IN TIME AT WHICH THE CUMULATIVE CASH FLOW TURNS POSITIVE
- EXAMPLE:
IN THE CUMULATIVE CASH FLOW EXAMPLE ABOVE, THE BREAKEVEN POINT IS 6 YEARS FROM START

EXAMPLE:

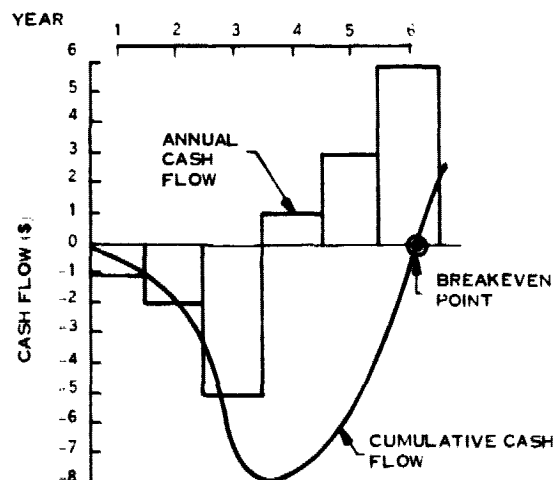


Fig. 14 Definitions of Financial Measures

EARLY USER PROGRAM INTEGRATION AREAS	POTENTIAL APPROACHES FOR EARLY USER PROGRAM INTEGRATION	IMPACT ON INTEGRATION FUNCTION	STATUS/REMARKS
PLANS, SCHEDULES	- MUTUAL EDUCATION - JOINT STUDIES - PERSONNEL EXCHANGE - INTENSIVE PUBLIC RELATIONS PROGRAMS - USER HANDBOOK/BUSINESS PRACTICES HANDBOOK	MAJOR EFFORT, NEW CAPABILITIES NEEDED (PR, HANDBOOK EDITING, ETC.)	- TYPICAL STUDIES ON-GOING (BUS, TERSEGE) - SHUTTLE, SPACELAB ACCOMMODATIONS DOCUMENTS GOOD BASELINE - NEED USER ORIENTATION.
	MAKE USERS PARTY TO PLANNING, SCHEDULING	- INCREASES NASA/USER INTERFACES, WORK FORCE - REQUIRES CREDIBLE STS (AND ELEMENT) PLANS AND SCHEDULES - REQUIRES UNIFORM PAYLOAD (AND ELEMENT) PLANS AND SCHEDULES	- TYPICAL STUDIES (BUS, TERSEGE) - SCIENTIFIC COMMUNITY WELL ON-BOARD
DECISIONS	AS ABOVE	"TRACKING" AND ASSESSMENT OF EFFECTS OF CHANGES INCREASES COMPLEXITY AND AMOUNT OF WORK	- INDUSTRY HAS ANALOGOUS PROGRAMS - COMPUTERIZATION COULD HELP - CREDIBILITY OF PARTICIPATION IN COMMERCIAL SPACE PROGRAMS HINGES ON THIS EFFORT - NEAR-REAL TIME 2-WAY COMMUNICATIONS VITAL
PRIORITIES	- DEVELOP METHODOLOGY EARLY - PUBLISH, EXERCISE - ENGAGE IN ACTIVE REVIEWS, CRITIQUES - UPDATE/REVISE, REPUBLISH	- ENCOURAGE/PERFORM DEVELOPMENT - EXERCISE, REVIEW REQUIRES TIME AND WORK FORCE - FIRST INTEGRATOR/USER INTERACTION	- MANY SCHEMES EXIST (SPACE STATION, ETC.) - ACTIVE REVIEW VITAL, SEEK DEVIL'S ADVOCATES, IF NECESSARY - PUBLICIZING VITAL

Fig. 15 Potential Approaches for Integrating Commercial Payload Program Plans, Schedules and Decisions, and Establishing Payload Priorities

- Perhaps the major integration task in these "paperwork" areas is that of prioritization. The ordering and ranking of experiments and payloads across disciplines, technologies, business areas, sociological parameters, etc is bound to be highly subjective. As such, each time a prioritization has been completed, there are bound to be a host of disappointed Users. Since there are few absolutes in the assessment of priorities, the most expeditious approach is to develop and publish, as early as possible, a prioritization methodology, complete with necessary criteria and weighting factors. After wide distribution of the method, its exercise on an available payload model, and wide distribution of its results, the subsequent comments and critiques can be utilized to update/revise the method. Two or three such cycles should reduce the number of later complaints. Of course, to obtain a

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meaningful response, the payloads involved should include specific payloads identified by specific commercial, Governmental, scientific, etc. Users, and the resulting priorities should be reviewed by those Users.

In all, these early integration areas are of less User concern, at present, than those mentioned previously. In the long run, however, the problems involved will require solutions, to which the payload integration function must contribute.

SUMMARY AND CONCLUSIONS

As a result of a preliminary review of the impacts of commercial payloads on integration functions of Spacelab programs, we have noted that concerns which affect the User are primarily economic in nature.

The specific factors of payload integration which rouse the potential User's economic concerns cover a wide range from the obvious costs and charges of Shuttle/Spacelab utilization, to the less obvious maintenance of valuable proprietary data. Some of the User's concerns are relatively common to industrial ventures, such as plans, schedules, and decisions, and their timing; while others are unique to space payloads, such as the question of priorities for early flights.

We have also listed some possible ways in which NASA can aid in reducing those concerns. Many of these potential solutions involve opening communications with potential Users, developing early relationships with them, and beginning to "learn" each others language. Such projects are underway in several areas, notably in space processing and earth resources. These should be expanded and additional efforts should be made to extend such activities to other potentially commercial disciplines.

Our results indicate that, in its broad sense, payload integration, requires early accomplishment of a number of "paperwork" tasks before any payload hardware is in evidence. There appears to be a sufficient quantity and variety of work that a major effort should be initiated soon, in order that the "building"

of a commercial User constituency can be accomplished in time for Spacelab operations.

Finally, we have noted that much of the required early integration effort need not start from scratch. For many of the identified problem areas, existing or analogous methods should be reviewed for possible use or extension to this effort.

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